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CHAPTER 7: BACKWATER PRODUCTIVITY

INTRODUCTION

The highly ephemeral nature of backwaters, the principal habitat for young-of-year (yoy) Colorado pikeminnow and other native fishes, is well known to Upper Basin researchers. Storm events within the San Juan River Basin are common during the summer-autumn monsoon season (typically July to October). These storms have caused discharge spikes in excess of 8,000 cfs during the recovery program and are often accompanied by large inputs of suspended sediment from various tributaries. The combination of these pulses of discharge and sediment have strong implications for the stability and productivity of backwaters and therefore the suitability of these habitats for pikeminnow yoy and young of other native fishes. Pikeminnow yoy may be particularly vulnerable to these effects because adults spawn typically in mid-July, later than other native fishes such as bluehead sucker which spawn from about May through June. Hence, pikeminnow yoy are generally more prevalent in these habitats during this monsoonal period than earlier spawning fishes and are also relatively smaller sized due to the later spawn, factors which may predispose these individuals to higher risk of downstream displacement.

Storm events can impact the quality of backwater habitats in several ways. One potential impact is a decrease in backwater depth caused by the gradual filling of these habitats with fine sediments. This phenomenon occurs naturally due to background suspended sediment loads, but can be accelerated greatly by storms. Water depth has been determined to be an important factor in the usage of backwaters by pikeminnow yoy in other Upper Basin studies (Holden 1977, Tyus and Haines 1991). In studies on the lower Green River, pikeminnow yoy were significantly more abundant in backwaters greater than 0.3 m than those less than that depth (Melissa Trammel, Utah Division of Wildlife Resources, pers. comm.). Thus, filling of backwaters following storms may reduce the availability and suitability of these habitats for this life stage. Additionally, storms can disrupt algal and invertebrate production through a variety of mechanisms. These mechanisms include the physical displacement of organisms, the smothering of periphyton (algae) and invertebrates via sediment deposition, or simply through a temporary reduction in primary productivity caused by increased turbidity.

Zooplankton and benthic invertebrates (primarily chironomids) are the major food sources for pikeminnow larvae and yoy, respectively (Vanicek 1967, Osmundson and Kaeding 1989). Stable flows should increase growth rates of these fishes by increasing the abundance of those food organisms. Improved growth should benefit these fishes by reducing susceptibility to predation (Kaeding and Osmundson 1988, Bestgen et al. 1997) and by improving overwinter survival (Thompson 1989, Bestgen 1996, Cargnelli and Gross 1997). So, developing a greater understanding of how the frequency and severity of storms affects the quality and productivity of these habitats should be important information for use in the recovery of this species. Management options may exist to ameliorate these negative effects.

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The objectives of this study were to: (1) determine whether and to what degree storm events affect various measures of backwater productivity; (2) determine whether longitudinal patterns in various measures of backwater productivity existed; and (3) determine whether various measures of productivity in San Juan River backwaters differed from those in pikeminnow nursery areas of the Colorado and Green Rivers.

STUDY AREA

A study was initiated in the summer of 1995 to address the preceding objectives. To facilitate research efforts the San Juan River was divided into four non-contiguous, arbitrary reaches, which were delineated as follows: Reach 1 (RM 224-195), or Navajo Dam to Bloomfield bridge; Reach 2 (RM 158-119), or Hogback to Four Corners bridge; Reach 3 (RM 93-52), or Montezuma Creek bridge to Mexican Hat; and Reach 4 (RM 40-2), a canyon-bound reach ending at Clay Hills Crossing. However, once the study was underway, the data was analyzed utilizing the eight geomorphically unique reaches identified earlier that year (Bliesner and Lamarra 1995) to maintain consistency with other studies (Figure 1.1). Beginning in 1996, sampling in Reaches 7 and 8 was discontinued due to a shift in research emphasis by the recovery program. Sampling occurred at various times (approximately monthly) prior to, usually during, and then after the monsoonal seasons in 1995, 1996, and 1997 and prior to runoff in the springs of 1996 and 1997. Table 7.1 presents a summary of the timing of sampling trips and the number of backwater habitats sampled during each trip by geomorphic reach.

The geomorphology of the San Juan River changes considerably throughout its course. Reach 1 is a canyon-bound reach, heavily influenced by the elevation of Lake Powell (Figure 1.1). It is the lowest gradient reach of the river, most similar in gradient to Colorado pikeminnow nursery areas on the Colorado and Green Rivers, and contains numerous migrating sand bars. Backwaters within this reach are associated with these bars at reduced discharge and more so with side canyon mouths at higher flows. Reach 2 is also completely canyon-bound, but is generally narrower, steeper, and more meandering than Reach 1. Due to these factors, backwaters are typically scarce and usually associated with side canyons or debris fans. Reach 3 is a broad floodplain, braided channel with relatively low gradient, high sinuosity, and a high percentage of sand substrate. Backwaters are usually associated with main channel bars and side channels, although several major tributaries enter the river in this reach and produce backwaters at higher flows. The surface area of backwaters can be the highest in the river in this reach, however, these backwaters are also the most susceptible to filling by storms as well. Reach 4 is somewhat of a transitional reach with moderate gradient, sinuosity, and braiding. Backwaters are relatively scarce in this reach and are mostly associated with cobble and sand bars and secondary channels. Reach 5 is a highly braided reach, steeper than downstream reaches, with dense riparian habitat consisting mainly of Russian olive and more cobble and gravel than downstream reaches. Backwaters are less easily perturbed by storms in this reach and are associated with both secondary channels and cobble/sand bars along the shoreline and in the mid-channel. Reach 6 is a much more channelized section of river that is fairly steep, containing high percentages of cobble and gravel substrate and relatively few backwaters. The Animas River enters at the upstream extent of this reach. Like Reach 6, Reach 7 is highly channelized, but has a more armored cobble bottom and is generally less turbid. Again, backwaters are quite scarce in this reach, typically associated with cobble and sand bars, and less susceptible to perturbation. Reach 8 occurs immediately below Navajo Dam and thus is most directly affected by its operation. It has the least turbid, coldest water of any of the reaches and is primarily a single channel with little braiding. A number of its backwaters have been created or altered by human activity. The uppermost section of this reach occurs upstream of any tributaries and is managed as a blue ribbon rainbow trout fishery (Bliesner 1999a).

Sampling occurred in the Colorado River for all 12 trips during which sampling occurred in the San Juan; however, since only one backwater was sampled on the Colorado during each of the first four trips, these data were not included. Two to six backwaters were sampled on any given trip between the Highway 191 bridge west of Moab, Utah, to just below Potash boatlaunch, approximately 18 miles downstream. This reach is located within a general area where capture rates of young pikeminnow are relatively high (McAda et al. 1994). Sites were accessed with a motorized raft. This is a relatively low gradient stretch of river (- 1-3 ft/mile) dominated by slow, sand-bottomed runs and intermittent sand bar complexes.

Table 7.1 The number of backwaters sampled per geomorphic reach from 1995 through 1997 by dated and numbered sampling period. Mean discharge (Q) during each trip as measured at Four Corners, New Mexico (USGS no. 09371010) is also indicated.

YEAR	TRIP DATE	TRIP #	GEOMORPHIC REACH 1	2	3	4	5	6	7	8	MEAN Q (cfs)
1995	August 4-12	1	1	1	4	2	3	1	3	1	1356
	September 6-15	2	2	3	4	2	3	1	3	1	1475
	November 2-8	3	2	2	3	2	3	1	3	1	1096
1996	April 15-19	4	4	4	4	4	4	4	NS	NS	583
	July 22-25	5	2	1	4	4	4	4	NS	NS	514
	August 26-29	6	3	3	4	4	3	3	NS	NS	1313
	December 2-6	7	2	1	4	3	4	3	NS	NS	901
1997	February 5-10	8	2	0	2	2	3	1	NS	NS	898
	April 22-23	9	1	1	3	3	1	3	NS	NS	1663
	August 12-13	10	1	1	4	2	2	2	NS	NS	2998
	September 16-18	11	3	1	3	4	3	0	NS	NS	3527
	October 20-22	12	3	0	2	4	2	2	NS	NS	1278

NS = not sampled

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Sampling on the Green River did not commence until the third year, during trips 9-12 (see Table 7.1). Two to four backwaters were sampled during each trip from Mineral Bottom boatlaunch (near Dead Horse Point, Utah) upstream about eight miles. The physical characteristics of the Green River in this area are very similar to the Colorado River stretch described above, but with generally more side canyons. Sampling usually occurred in backwaters within these side canyons, as these were often the only habitats available; whereas sampling in the Colorado usually occurred in backwaters associated with main channel sand bars. This reach also occurs within a larger area known to provide good nursery habitat for young pikeminnow (McAda et al. 1994).

A variety of physical and biological parameters were measured in backwater habitats. Physical parameters included: (1) water depth; (2) total suspended solids; (3) dissolved oxygen; and (4) temperature. Water depth appears to be important to some fishes and might be negatively affected by storms. Total suspended solids is an indirect measure of potential sediment-related impacts of storms on primary and secondary productivity. Dissolved oxygen and temperature are basic water quality parameters that could also influence habitat suitability for fishes. Measures of productivity included: (1) phytoplankton biomass; (2) zooplankton abundance; (3) periphyton biomass; (4) benthic invertebrate biomass; and (5) benthic detrital biomass. Phytoplankton abundance is an indirect measure of backwater stability, as higher levels are usually present under more stable conditions, and it also represents a food source for herbivorous zooplankton. Periphyton, detritus, benthic invertebrates, and zooplankton represent potential food sources for young native fishes. A detailed description of the methodology employed in the measurement of these parameters follows in the Methods section.

METHODS

Water depth (m)

Taken at three equidistant points along each of four equally spaced transects using a stadia rod and measured to nearest 0.01 m. Transects range from the mouth (T1) to the closed end or toe (T4) of the backwater. Mean water depth in each backwater was calculated using these 12 measurements.

Total Suspended Solids (mg/L)

Water samples were taken at transects T2, T3, and T4 and composited in a 1-pint bottle. Subsample of 100 ml was filtered, oven-dried at 40^{o} C, and weighed to nearest mg.

Temperature (^{o}C)

Taken at every point in which water depths were taken (total 12 points per backwater) and also in adjacent river using Hydrolab unit.

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Dissolved oxygen (mg/L)

Measured at the midpoints of transects T2 and T4 and also in river adjacent to backwater with Hydrolab unit.

Phytoplankton (µg/L)

Water samples were collected just below the water surface with ½-pint plastic bottles at transects T2 and T4. These samples were wrapped in aluminum foil and frozen. The samples were thawed and filtered in the laboratory for analysis of chlorophyll a content using a spectrophotometer.

Zooplankton (#/m^3)

Horizontal plankton tows were pulled just beneath the water surface. Net aperture was 11.2 cm diameter (0.01 m^2 area). One tow was pulled at transects T2 and T4, or wherever water was deep enough to sample. Distance of tow was recorded to calculate total water volume sampled. Samples were rinsed into whirl packs and preserved in isopropyl alcohol for later enumeration.

Periphyton (mg/m^2)

Sampled with 1.25-inch diameter clear plastic tube. Inserted just below the substrate, the core was lifted out intact by keeping hand over the bottom of the sampler. Core could be viewed from the side and was slowly removed with only uppermost layer of periphyton-covered sediment retained. Samples were stored in aluminum-wrapped whirl packs and placed on dry ice. Samples were collected at transects T2 and T4. Chlorophyll a content was determined using a spectrophotometer.

Benthic invertebrates (g/m^2)

Sampled with Ekman-type dredge at midpoint of transects T2, T3 and T4. Each sample encompassed an 18.6 cm x 14.4 cm, or 0.027 m^2 area. Samples were placed in zip-lock bags or jars and preserved in isopropyl alcohol. Biomass was determined by first measuring the volume of invertebrates (ml) per sample in the laboratory. A relationship was then established between volume and total dry weight (to nearest 0.1 g) of invertebrates for a subset of the total samples collected. This mathematical relationship was then applied to volumes determined for the remaining samples.

Detritus (g/m^2)

Coarse and fine particulate organic matter found in benthic invertebrate samples was separated from inorganic material, oven-dried at 60^o C, and weighed to the nearest 0.1 g.

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Sediment (% dry wt.)

Collected within approximately the upper 15 cm of substrate in the backwater with 5-cm diameter coring tube. Sample was stored in a zip-lock bag, oven-dried at 60°C, and sieved. Each size fraction was weighed to the nearest 0.1 g.

RESULTS

Hydrology

San Juan River

Considering that discharge played such a large role in the findings of this study, it is worth first considering the timing of sampling trips relative to the hydrograph. A total of 12 sampling trips occurred over the 3-year study. The timing of these trips is superimposed over the San Juan River hydrograph for the 1995 to 1997 period (Figure 7.1). The first series of trips in 1995, which followed an above average runoff (1,625,000 ac-ft for March-July period), occurred prior to (August), during (September), and after (November) what could be considered a relatively mild monsoon season compared to what was observed in the subsequent two years. The next sampling trip in April, 1996, preceded a below average runoff (432,000 ac-ft) and followed the longest storm-free period (5½ months) observed during the entire study. Sampling occurred again after runoff in July on the descending limb of a small storm, in August at the peak of a larger storm, and again in December at base flow, but following several large storms. Sampling occurred two months later in February, 1997, immediately following a small storm, and again in April after a series of large storms, prior to the bulk of runoff. The volume of runoff in 1997 (1,319,000 ac-ft) was nearly equal to 1995. Lastly, sampling occurred throughout the 1997 monsoon season in August, September, and October. The first two trips occurred during large storms, while the last occurred after the end of the monsoons (Figure 7.1).

In summary, sampling occurred throughout three consecutive monsoon seasons from 1995 to 1997. Ranked in terms of both the frequency and magnitude of storm severity, 1995 ranked as the least severe and 1997 as the most severe, with 1996 being intermediate but closer in severity to 1997. Backwater conditions were determined in the spring of 1996, following a long storm-free period, and again in 1997 following a fairly intense period of storms (Figure 7.1). Additionally, sampling in 1995 occurred after a relatively large runoff. According to detailed HEC-6 modeling studies undertaken during the San Juan River Recovery Implementation Program, discharges in excess of 5,000 cfs are needed for a minimum of 21 days to thoroughly purge backwaters throughout the entire river of fine sediment (Bliesner 1999b). This discharge was exceeded during 72 days in 1995 (March-July period); hence, backwater cleaning occurred that year. In 1996, however, the threshold of 5,000 cfs was never exceeded, and thus cleaning did not occur. During 1997, there were a total of 49 days in excess of 5,000 cfs, and so removal of fine sediments from backwaters should have occurred that year also.

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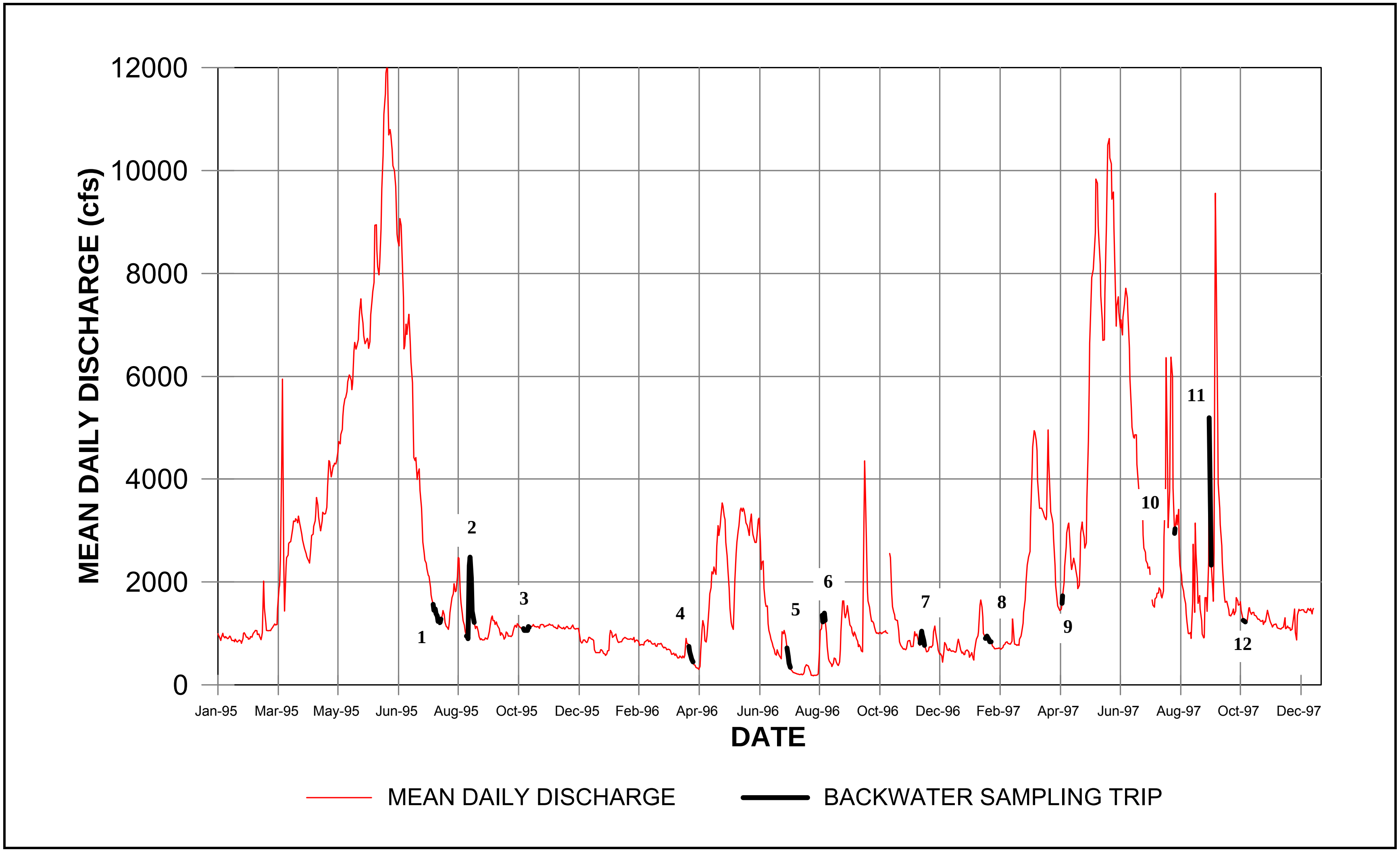

Figure 7.1. **San Juan River Mean Daily Discharge for the 1995-97 Period as Measured at the Four Corners, New Mexico Gauge with the Timing and Numbering of Backwater Sampling Trips Indicated**

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Colorado and Green Rivers

Discharge during the same period of record (1995-97) for the Colorado and Green Rivers is indicated in Figure 7.2. As stated previously, sampling in the Colorado and Green Rivers occurred on trips 5-12 and trips 9-12, respectively. The timing of sampling trips 5-11 are superimposed on the Colorado River hydrograph. The last trip is not indicated due to unavailability of those flow records.

Similar to the San Juan River, discharge was greater in both rivers during 1995 and 1997 than in 1996. Discharge during the fall to spring period of 1996-97 on the Colorado River appeared to be fairly stable, a notable departure from the San Juan River during the same period when several large storms occurred (Figure 7.1). Sampling in the spring of 1997 (trip 9) occurred on the ascending limb of the hydrograph for both rivers. The first post-runoff sampling (trip 10) occurred during the peak of a substantial storm on the Colorado and a relatively weaker one on the Green River. The next trip took place a month later, immediately prior to large storms within both drainages. The last trip (not pictured) occurred shortly after those storms. Thus, during the last monsoon season when all three rivers were sampled, storms were prevalent in all of the drainages.

Backwater Quality/Productivity

To facilitate interpretation, analysis of the results of the backwater productivity studies is considered by each parameter separately. First, temporal and spatial trends within the San Juan River are presented using the entire data set or various subsets thereof, and then comparisons are made with backwaters sampled in the Colorado and Green Rivers for correspondingly sampled time periods.

Throughout this study, backwaters sampled in the San Juan River were relatively permanent in nature, defined as those that were present in at least two of three aquatic habitat mappings of the San Juan River conducted by Ecosystems Research Institute and Keller-Bliesner Engineering during October, 1993, and August and November, 1994. Ideally, the same backwaters would be sampled from one sampling period to the next for comparative purposes. This was accomplished whenever possible, otherwise alternate backwaters were selected when available. Selected backwaters were generally larger and deeper than the majority of backwaters, although this was not always the case. Thus, backwater selection during this study was not a random process. Practically speaking, considering their impermanent nature, the location and even presence of these habitats could not be relied upon. On a number of occasions, only one or no suitable backwater habitats could be found in some reaches, particularly Reach 2 (Table 7.1).

Water Depth

Mean (± 1 SE) water depth by trip for San Juan River backwaters is plotted in Figure 7.3. Levene's test for homogeneity of variance indicated unequal variances amongst the trips ($P<0.005$); therefore, a one-way analysis of variance (ANOVA) was used followed by Dunnett's multiple comparison C-test which does not assume equal variance. For future analyses, Tukey's Honest Significant Difference (HSD) multiple comparison test will be used in instances where equal variance between

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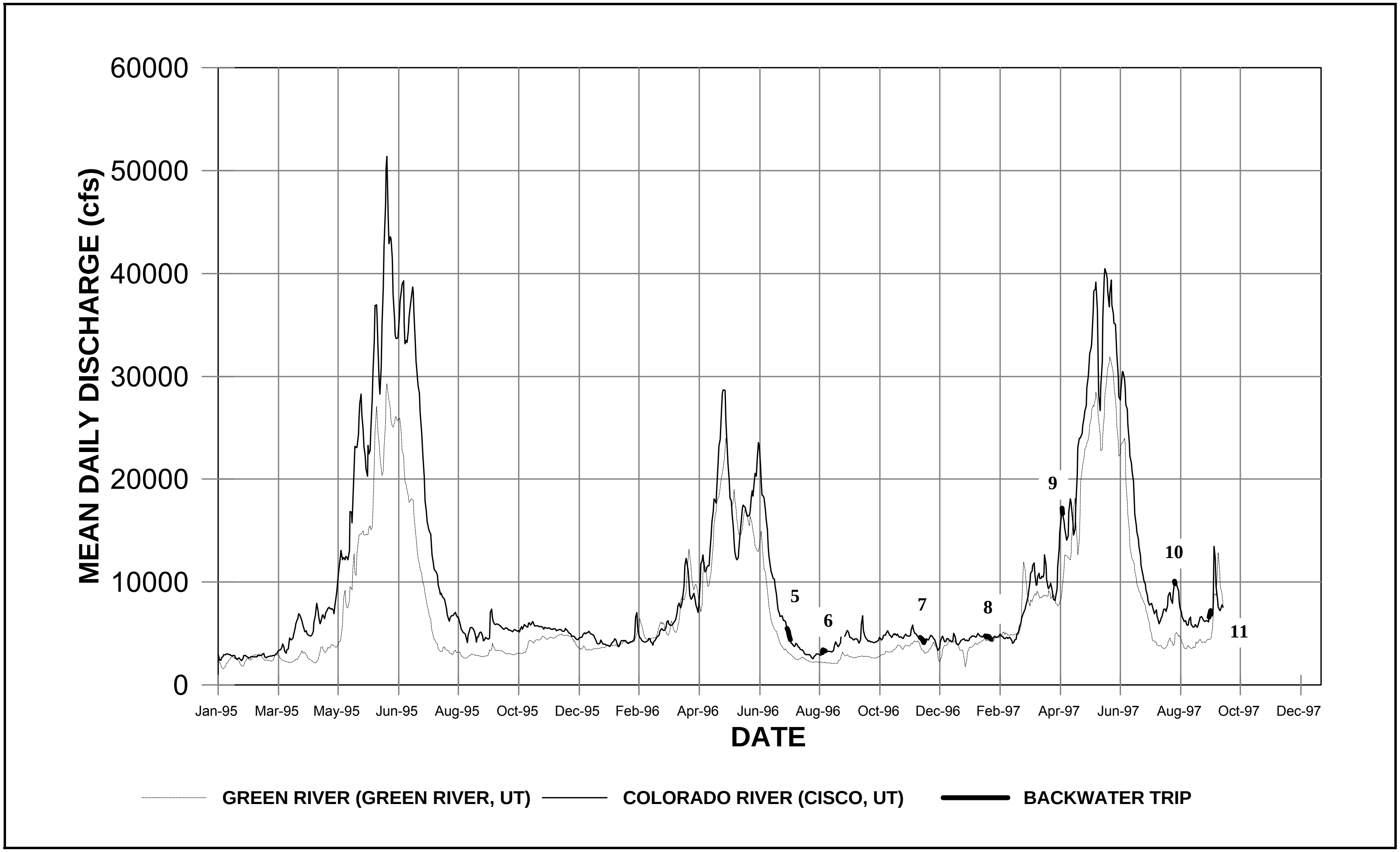

Figure 7.2. **Colorado River and Green River Mean Daily Discharge for the 1995-97 Period as Measured at the Cisco, Utah, and Green River, Utah Gauges with the Timing and Numbering of Backwater Sampling Trips Indicated**

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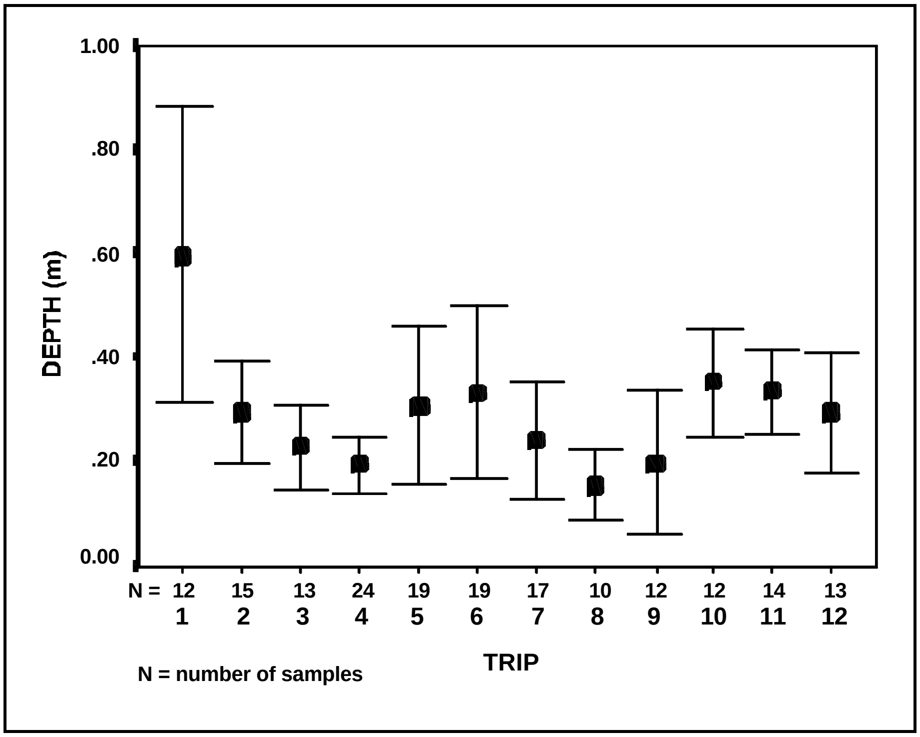

Figure 7.3. Mean Water Depth (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

treatments has been established. This is considered to be a moderately conservative analysis that is less sensitive to unequal sample sizes (Zar 1984). No significant differences in mean depth were detected between trips (P>0.05). However, there appeared to be generally greater, although highly variable, backwater depths during the first trip than in subsequent trips, particularly those that occurred prior to the following runoff (trips 2-4) (Table 7.1). As previously indicated, this first trip followed the highest volume of runoff experienced during the study and preceded a relatively moderate monsoon season (Figure 7.1). Although no pre-1995 runoff backwater data exists for this study, modeling studies would again predict that backwater flushing should have occurred that year (Bliesner 1999b). No flushing was evident in 1996 (trip 5) following a below average runoff and there appeared to be reduced and less variable backwater depth thereafter to the following late winter period (trip 8) (Figure 7.3). The degree of flushing following runoff in 1997 could not be assessed as post-runoff sampling in August (trip 10) and September (trip 11) occurred during elevated flows due to storms (Table 7.1). Thus, at those times, sampling actually occurred in recently formed backwaters not present during base flow conditions. Nevertheless, when comparing the late or post-monsoon period between all three years during base flow conditions (trips 3, 7, and 12), there were no differences detected (P>0.05). Backwaters averaged approximately 0.2-0.3 m at each of those times (Figure 7.3). Therefore, the severity of the monsoons appeared to have little effect on overall backwater depth by the end of the season when comparing between years.

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When averaged across all sampling trips, there were no significant differences detected in water depth between reaches (P>0.05; Dunnett C) (Figure 7.4). Although there was some trend toward deeper backwaters in the lower two reaches, greater depths in Reach 1 was likely contributed to by changes in the elevation of Lake Powell over the study period. Mean water depth was less than 0.5 m in all reaches for the entire study period, particularly so in upstream reaches.

Backwaters sampled within the low gradient pikeminnow nursery area of the Colorado River were significantly deeper (-0.55 m) than those sampled throughout the San Juan River (-0.3 m) when averaged for trips 5 through 12 (P<0.005; Independent samples t-test) (Figure 7.5). During trips 9 through 12, backwaters in the Colorado were again deeper than in the San Juan, averaging 0.9 and 0.3 m, respectively (P<0.05; Dunnett C), while those in the Green River were intermediate (-0.5 m) and not significantly different from either of the other systems (P>0.05) (Figure 7.6). It should be emphasized the presence or absence of storms and the magnitude thereof played a major role in the depths of backwaters measured during this last series of trips in all of the rivers sampled.

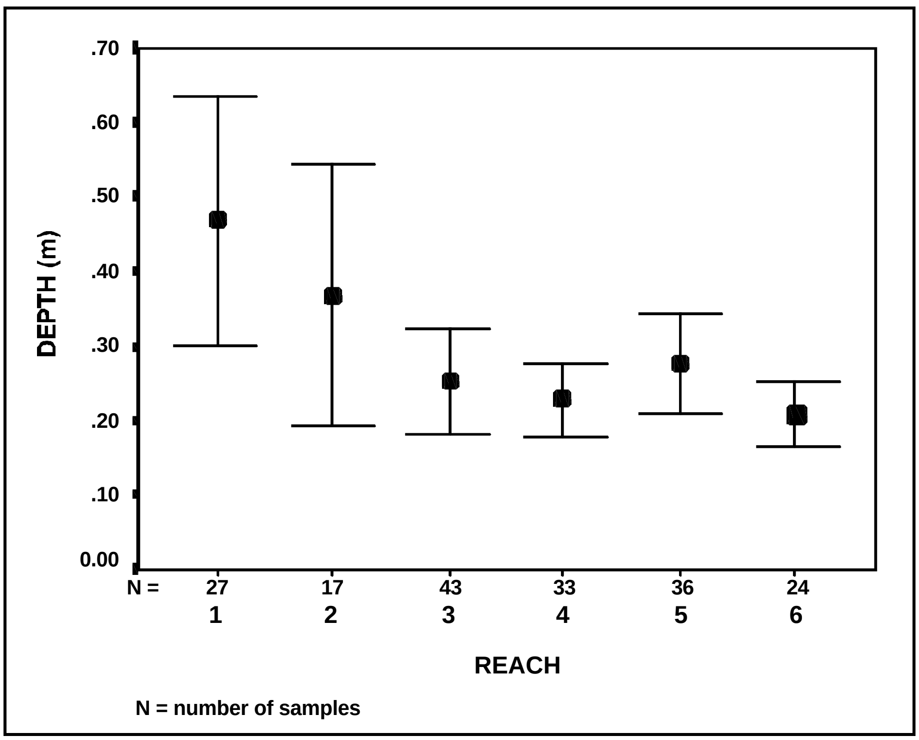

Figure 7.4. Mean Water Depth (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach

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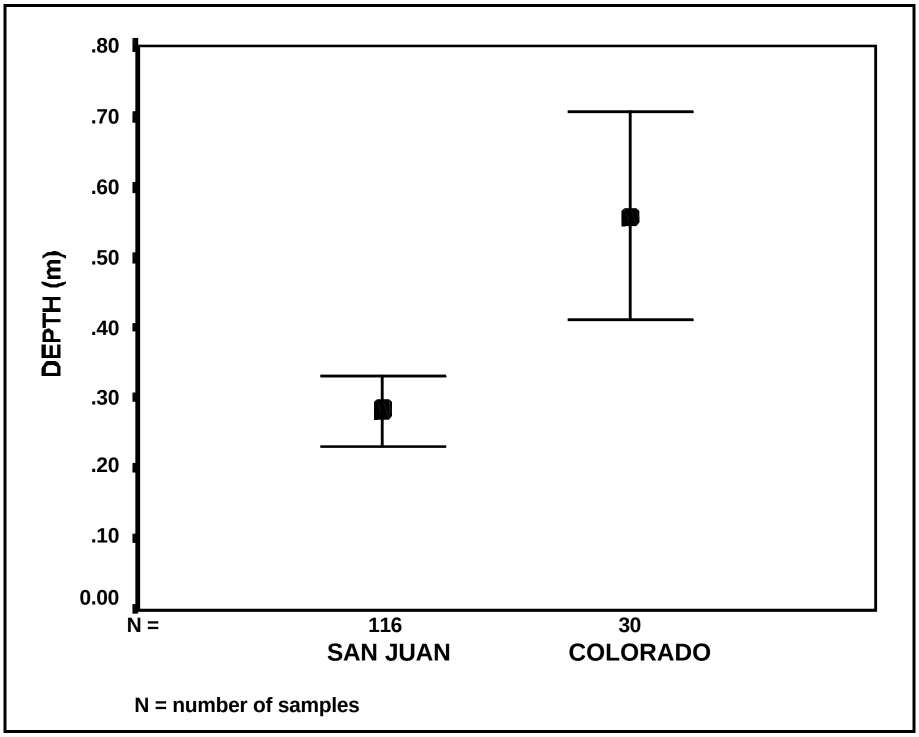

Figure 7.5. Mean Water Depth (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 12

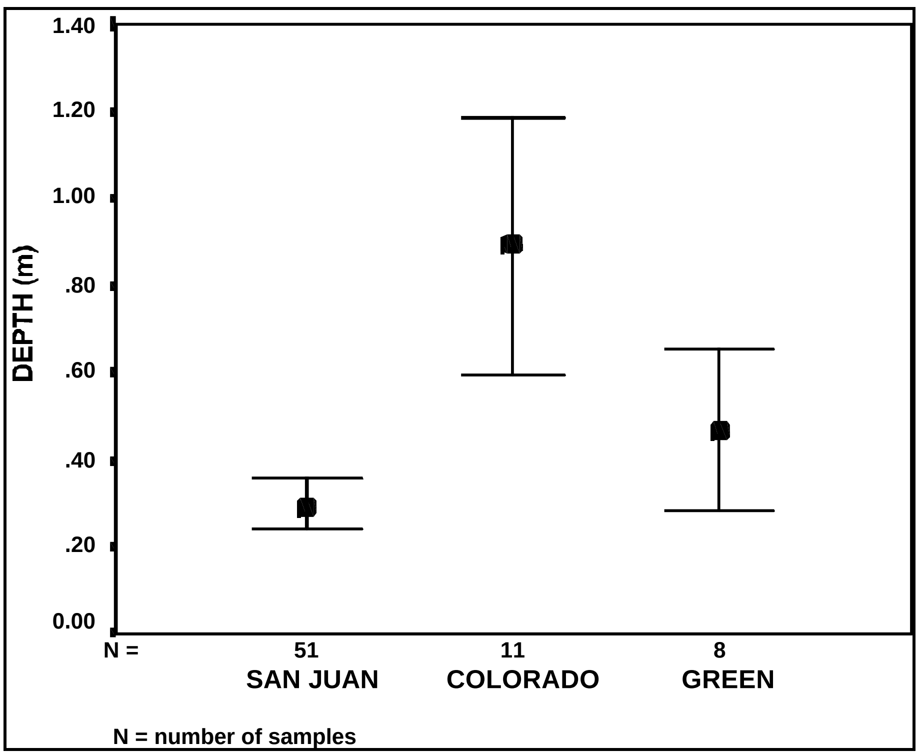

Figure 7.6. Mean Water Depth (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12

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Total Suspended Solids

Elevated concentrations (>200 mg/L) of total suspended solids (TSS) were observed during trips 2, 6, 8, 10, and 11 (Figure 7.7), all of which occurred during or immediately following storms (Figure 7.1). The highest concentration (-4,500 mg/L) was observed during trip 2 in September, 1995, when sampling occurred during a large storm. The lowest concentrations (<75 mg/L) occurred during trips 1, 3, and 4 under base flow conditions. Mean TSS concentrations following runoff in 1996 and 1997 during trip 5 (-150 mg/L) and trip 10 (-250 mg/L), respectively, were significantly greater (P<0.05; Dunnett C) than those detected following runoff in 1995 during trip 1 (-25 mg/L) (see Table 7.1). No storms occurred during or prior to trip 1 in 1995, while storms did occur during the post-runoff trips in 1996 and 1997 (Figure 7.1).

There was no relationship between discharge and TSS (Figure 7.8). Higher magnitude storms with respect to discharge did not produce higher levels of TSS. For example, intermediate discharges of about 1,500 cfs (Table 7.1) during trip 2 in September, 1995, produced very high TSS concentrations in excess of 4,000 mg/L, whereas discharges of about 3,000 cfs during trips 10 and 11 in 1997 resulted in only moderately high TSS levels of 250 to 500 mg/L (Figure 7.7).

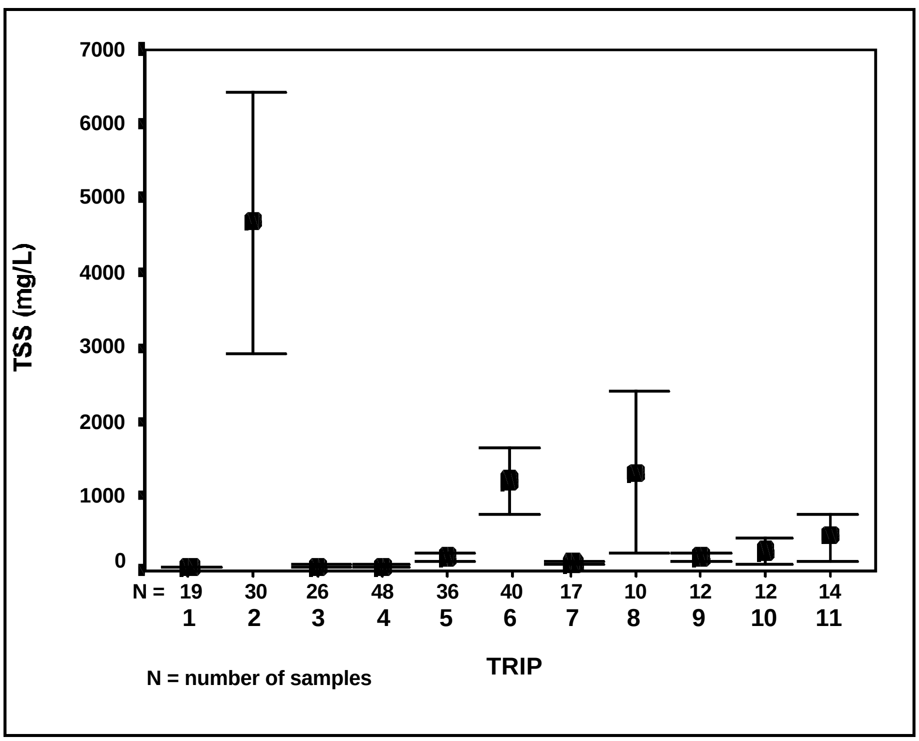

Figure 7.7. Mean Total Suspended Solids (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

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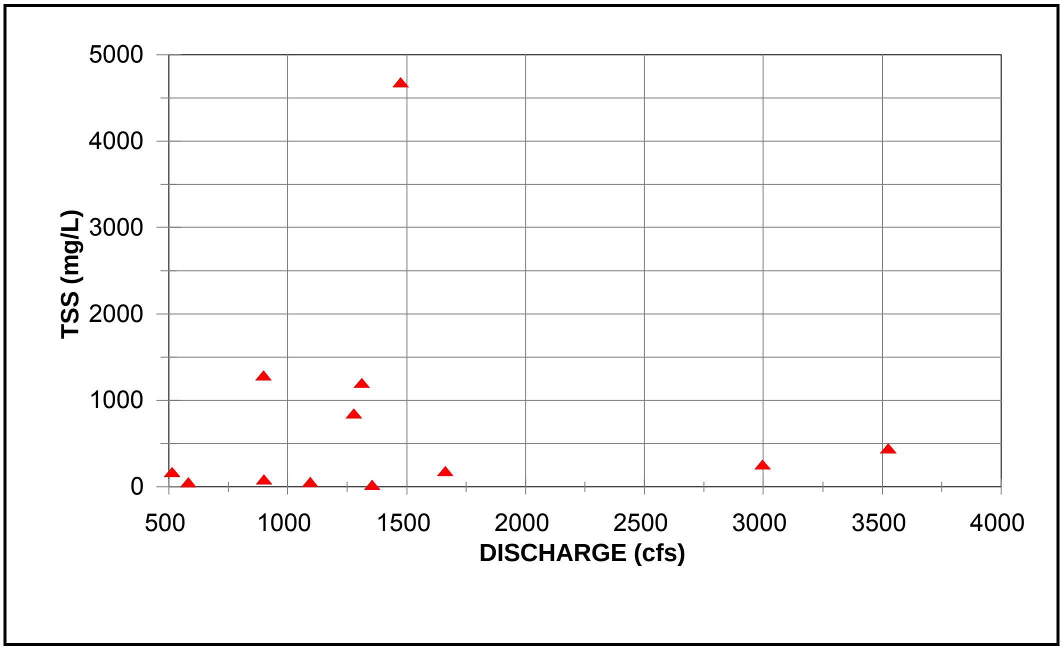

Figure 7.8. The Relationship Between Discharge and Total Suspended Solids in San Juan River Backwaters over the 1995-97 Period for Trips 1 through 12

TSS concentrations tended to be lowest in Reaches 5 and 6 overall and greater, although more variable, in downstream reaches; however, no differences were significant (Figure 7.9) ($P>0.05$; Dunnett C). The higher and more variable concentrations in the lower reaches was due primarily to the storm during trip 2 (Figure 7.1), which occurred after sampling in Reaches 5 and 6 had been nearly completed.

TSS levels were significantly greater in San Juan than Colorado River backwaters during trips 5 through 11 ($P<0.001$; Independent samples t-test; equal variance not assumed) (Figure 7.10). They averaged approximately 600 mg/L in the San Juan River and 100 mg/L in the Colorado River, and were considerably less variable in the Colorado. Inspection of the results by trip indicated that TSS levels were higher in San Juan backwaters during trips 5 ($P<0.001$; Independent samples t-test), 6 ($P<0.001$), 8 ($P<0.05$), and 9 ($P<0.005$) (Figure 7.11). Examination of the hydrographs for the San Juan (Figure 7.1) and Colorado Rivers (Figure 7.2) reveals that storms occurred during or immediately prior to those trips on the San Juan, but not on the Colorado. Storms occurred during or prior to sampling during trips 10 and 11 in both rivers when there was no significant difference in TSS levels detected ($P>0.36$; Independent samples t-test).

There was no difference in TSS concentrations between the San Juan, Colorado, and Green Rivers during trips 9, 10, and 11 when samples were obtained in all three systems ($P>0.66$; One-way ANOVA). Storms were prevalent in all three drainages over this period (Figures 7.1 and 7.2) when concentrations averaged about 250 mg/L.

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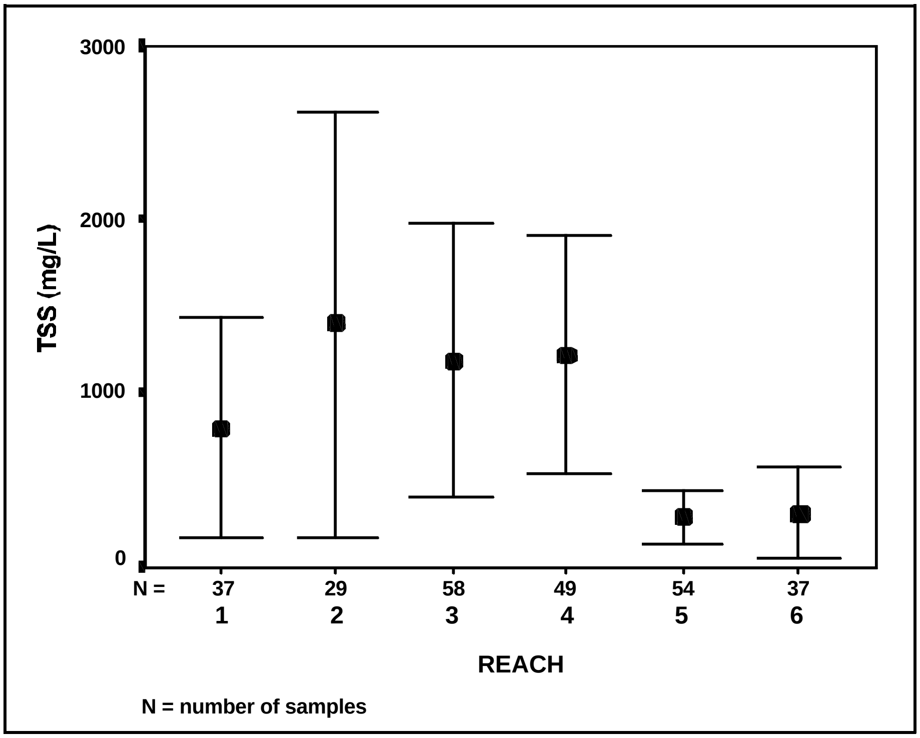

Figure 7.9. **Mean Total Suspended Solids (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach.**

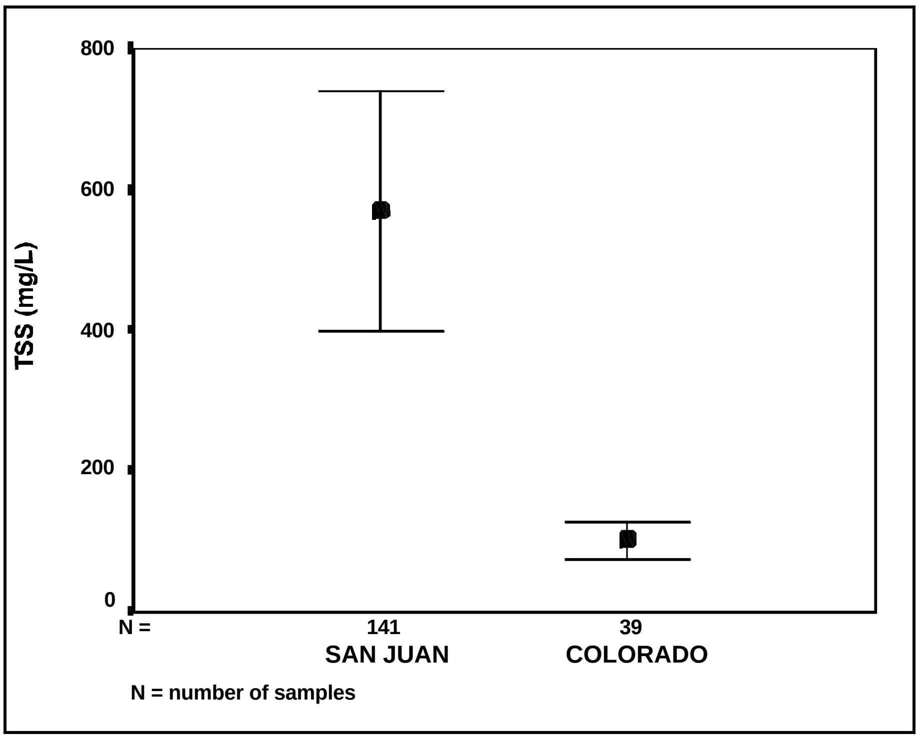

Figure 7.10. **Mean Total Suspended Solids (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 through 11**

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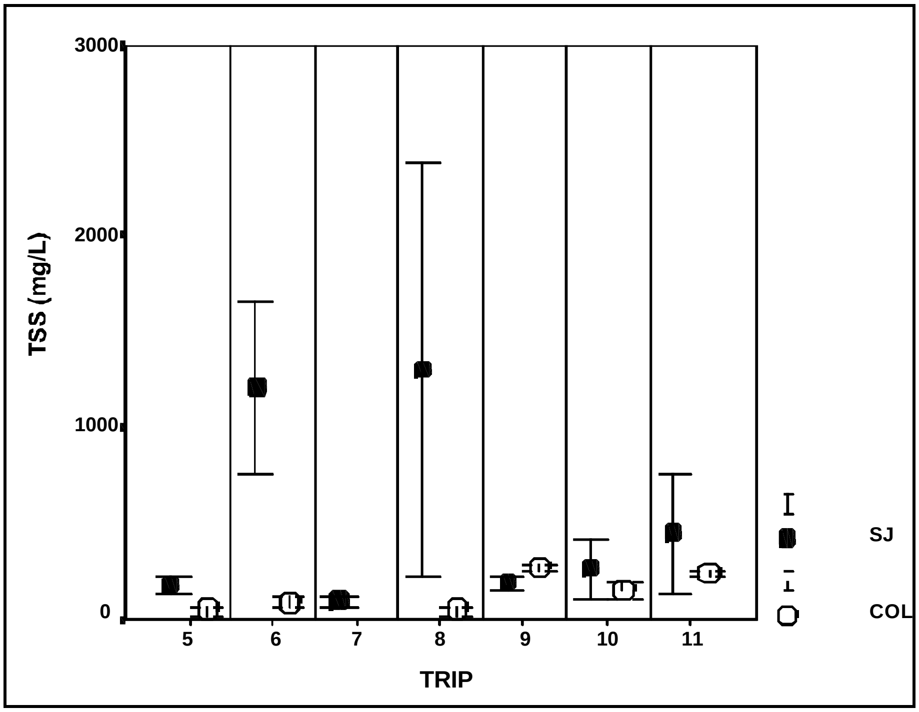

Figure 7.11. Mean Total Suspended Solids (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip

Temperature

The maximum summer temperatures observed in San Juan River backwaters averaged about 27°C and occurred during the July and August trips (Figure 7.12, Table 7.1). There was no difference between the temperatures observed during the August trips (1, 6, and 10) between years ($P>0.05$; Dunnett C). Hence, storms appeared to have little influence on backwater temperatures or such effects may have been obscured by climactic conditions. The coolest temperatures during the study were observed during the December, 1996 trip and averaged about 4° C. Many of the backwaters encountered at that time were partially or completely frozen. There were no temperature differences observed by reach when averaged across all trips ($P>0.70$; Tukey's HSD), although there appeared to be a slight depression in the canyon-bound Reach 1 (Figure 7.13).

A comparison of backwaters in the Colorado and San Juan rivers indicated that temperatures matched fairly closely through time (Figure 7.14). San Juan River backwaters were warmer than Colorado backwaters only during trips 8 ($P<0.05$) and 9 ($P<0.005$; Independent samples t-test) in February and April, 1997, respectively. When comparing all three rivers during trips 9-12, no significant differences in backwater temperature were found ($P>0.05$; Tukey's HSD), although temperatures in Colorado River backwaters were nearly less than those in the San Juan ($P=0.07$) (Figure 7.15).

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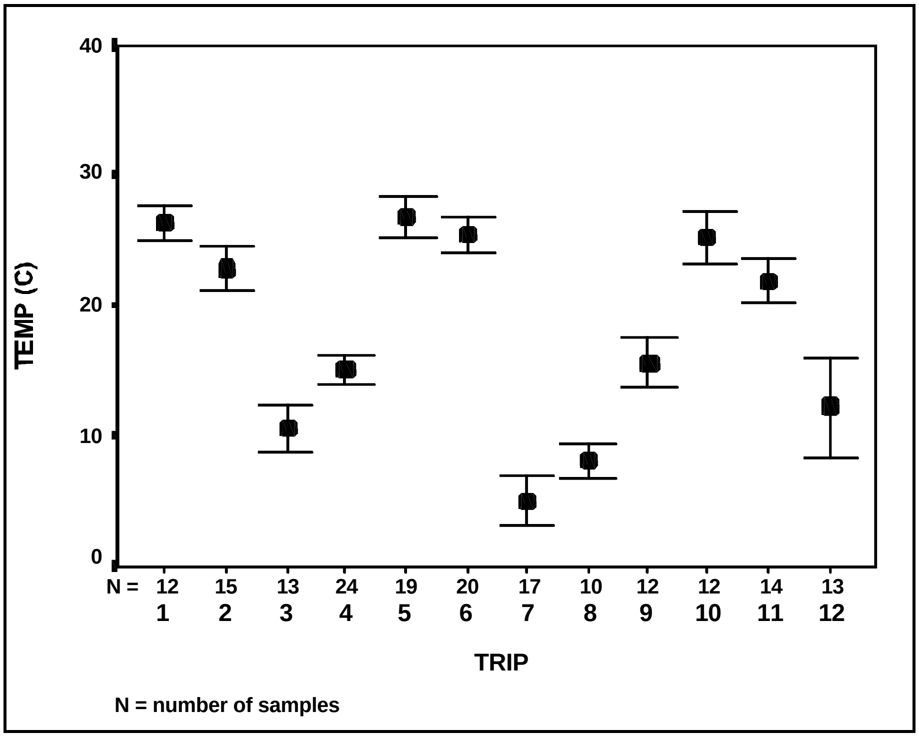

Figure 7.12. Mean Temperature (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

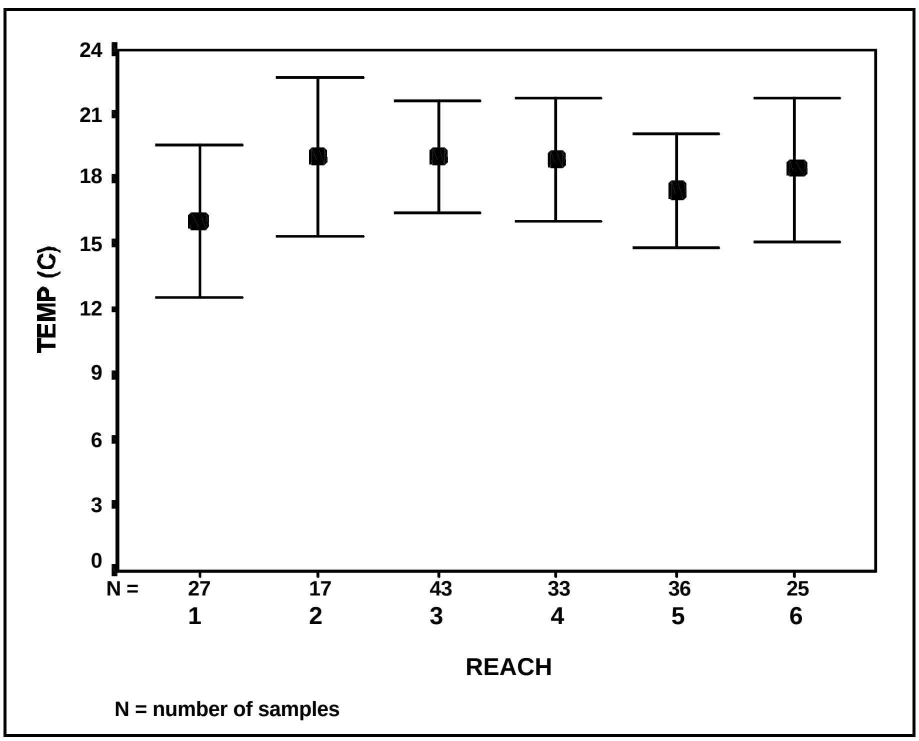

Figure 7.13. Mean Temperature (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach

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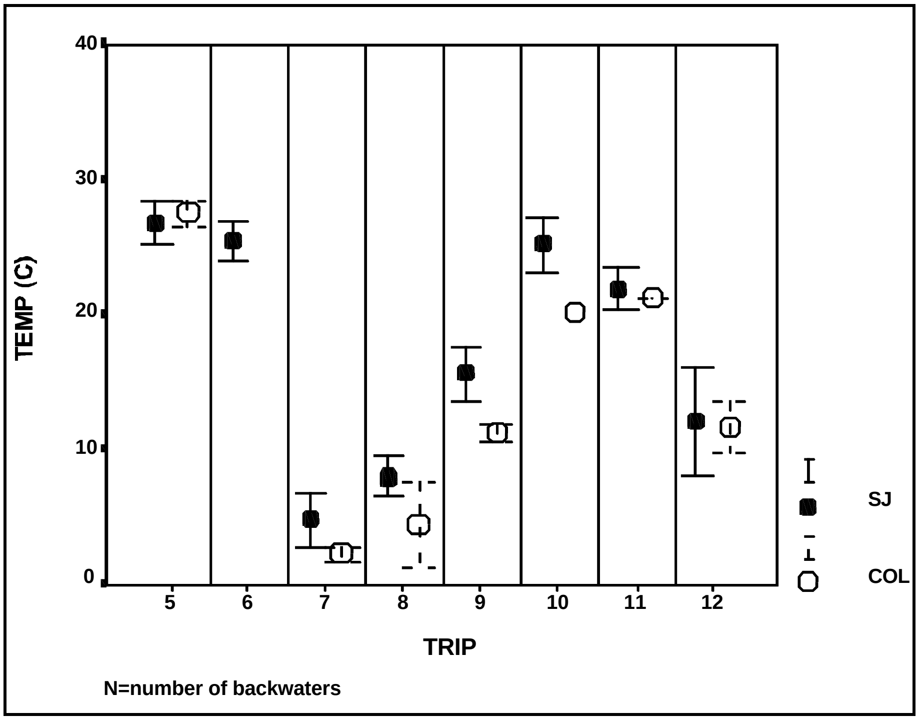

Figure 7.14. Mean Temperature (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip

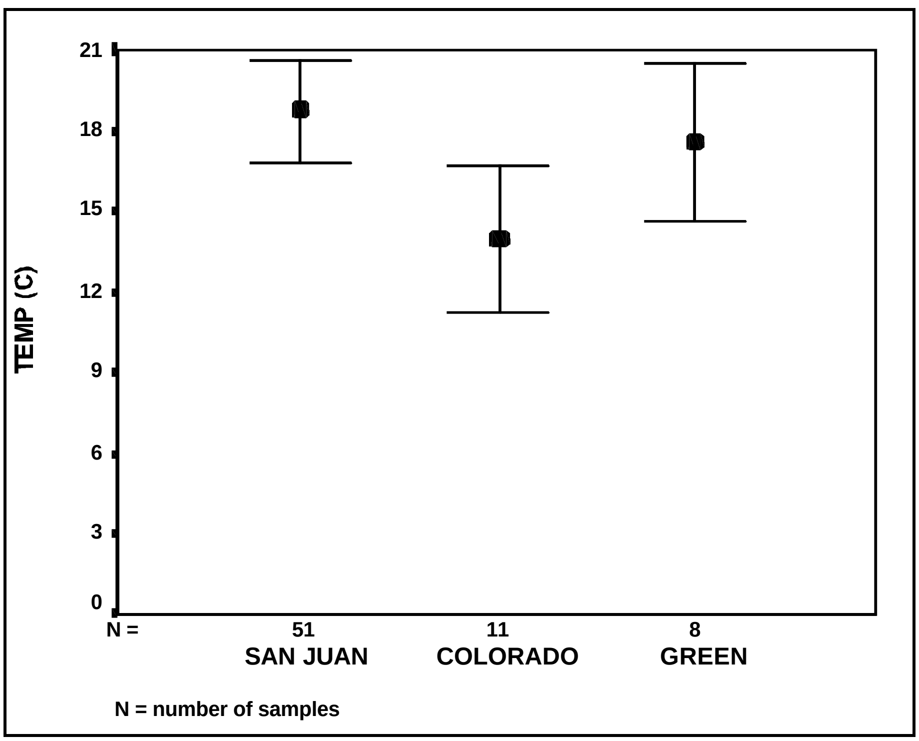

Figure 7.15. Mean Temperature (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12

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Dissolved Oxygen

Dissolved oxygen concentrations were generally highest in San Juan River backwaters during the cooler months of November to April (trips 3, 4, 7, and 9) and lowest during the warmer months of July to September (trips 2, 5, 6, and 10) (Figure 7.16). They ranged from a mean of 2.7 mg/L during August, 1997 (trip 10) to a high of 9.7 mg/L during December, 1996 (trip 7). Temperatures did not differ significantly between years during August trips ($P>0.05$; Dunnett C), nor did storms appear to consistently affect oxygen levels. For example, dissolved oxygen levels dropped significantly following a storm which occurred during trip 2 from unperturbated conditions observed during trip 1 ($P<0.05$). However, there was no difference found in oxygen levels between trip 5 which preceded a storm and trip 6 which occurred during a storm a month later ($P>0.05$). Dissolved oxygen did not vary by reach when averaged for all trips combined ($P>0.86$; Tukey's HSD).

Colorado River backwaters were more oxygenated than those in the San Juan River during trip 5 in July, 1996 and trip 8 in February, 1997 ($P<0.001$; Independent samples t-test); otherwise, there were no differences found ($P>0.30$) (Figure 7.17). Over the same period of time (trips 9-12) in 1997, Colorado River backwaters had higher oxygen levels than San Juan River backwaters ($P<0.05$; Dunnett C), while those in the Green River were more variable and not significantly different from the other two rivers ($P>0.05$) (Figure 7.18).

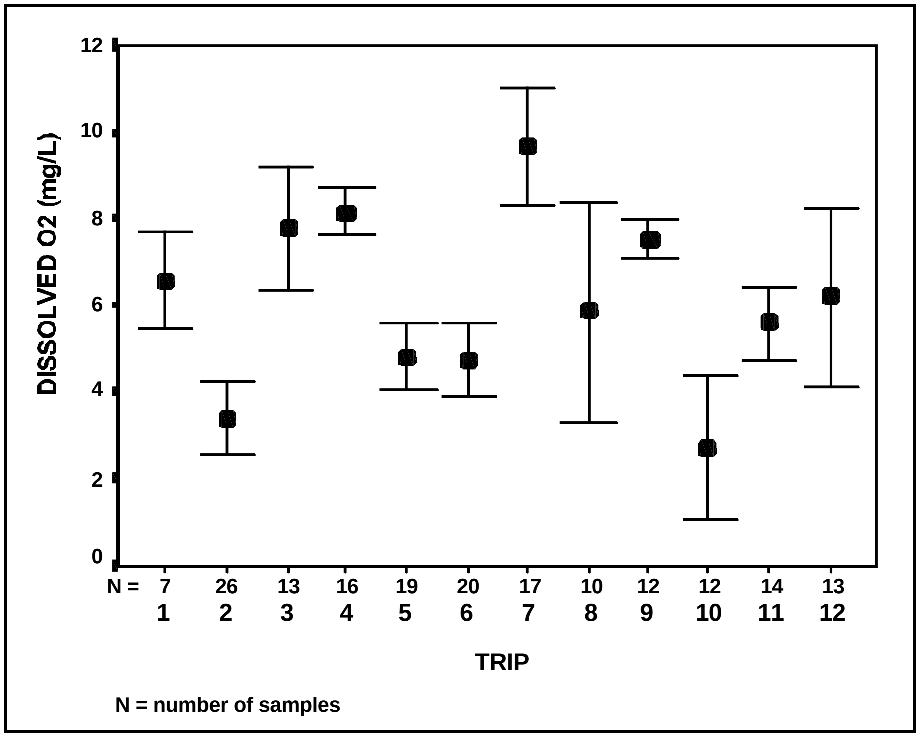

Figure 7.16. Mean Dissolved Oxygen (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

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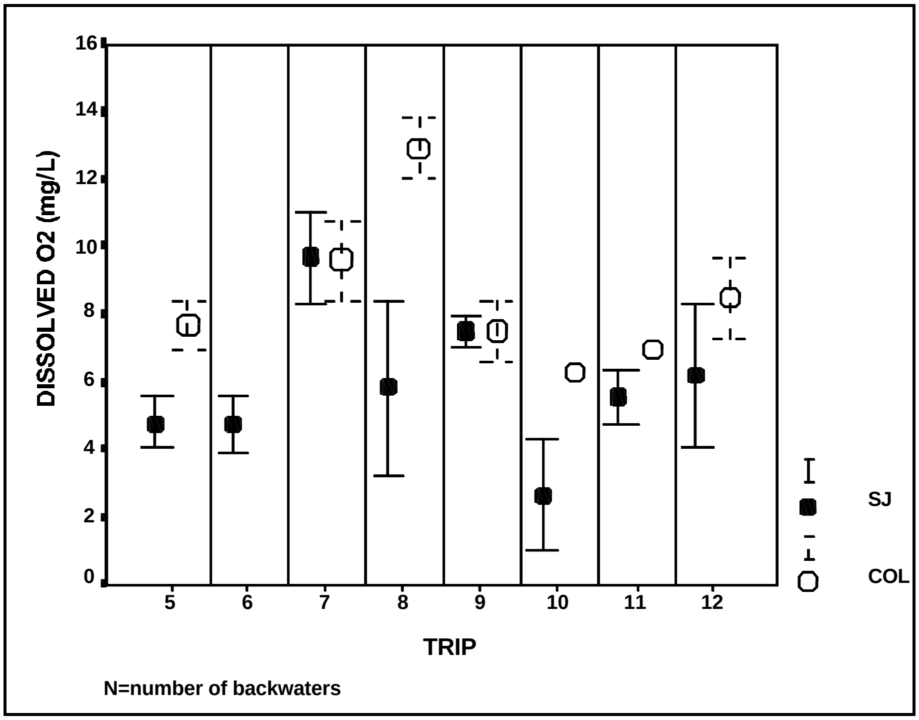

Figure 7.17. **Mean Dissolved Oxygen (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip**

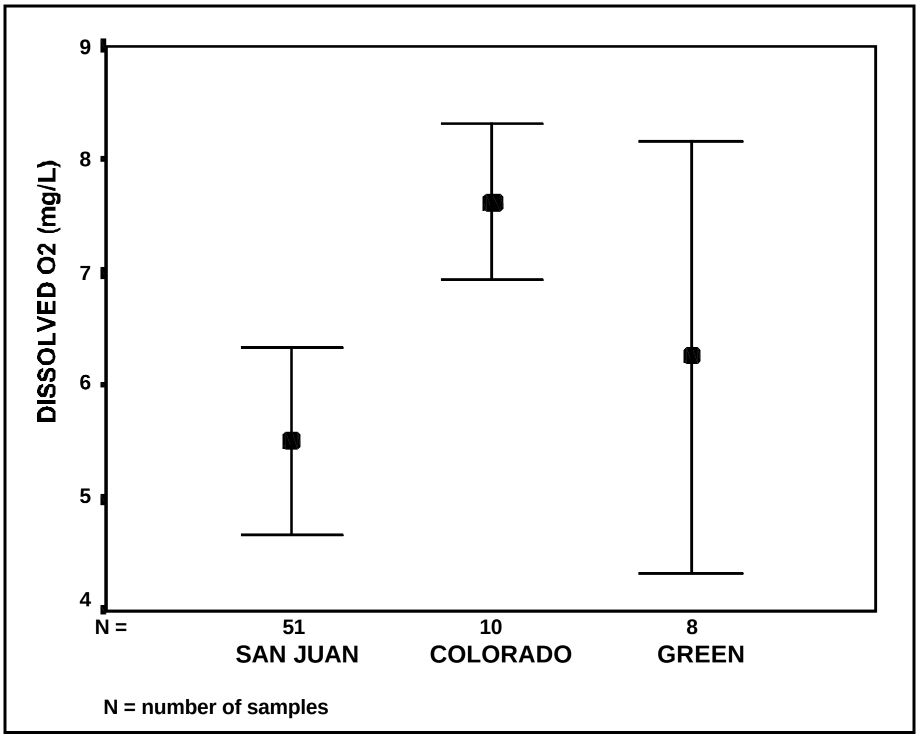

Figure 7.18. **Mean Dissolved Oxygen (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12.**

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Phytoplankton

Phytoplankton biomass was relatively low (<10 µg/L) during most of the San Juan River sampling trips (Figure 7.19). Periods of stability preceding sampling in 1995 and 1996 resulted in some increase in phytoplankton during trips 3 and 4 (see Table 7.1) over low, post-runoff levels observed during trip 1 in August, 1995 ($P<0.05$; Dunnett C). This trend is more distinguishable when examining a single backwater (RM 153) in Reach 5 sampled during the first four trips (Figure 7.20). The highest levels riverwide were observed during trip 8 in February, 1997 (Figure 7.19), although due to high variability it did not differ significantly from any other trips ($P>0.05$). Further analysis revealed that this high variability was due primarily to two backwaters sampled in Reach 1 (see Table 7.1), which ranged from about 10 to 70 µg/L, that were actually located in Lake Powell at RM -1. There was no difference between August trips from 1995 to 1997 ($P>0.05$), despite large differences in levels of total suspended solids between trips as noted above, which may affect production of phytoplankton by influencing light penetration. There were no differences in phytoplankton by reach when averaged across all trips ($P>0.05$) and Reach 1 was again found to be the most variable location (Figure 7.21).

A comparison of the San Juan to the Colorado River during trips 5 through 12 combined indicated that there was no difference between the two systems in phytoplankton biomass ($P>0.05$; Independent samples t-test) (Figure 7.22). Analysis of these data by trip indicated that phytoplankton was greater in Colorado River backwaters during trip 5 ($P<0.05$; Independent samples t-test), trip 6 ($P<0.001$), and trip 12 ($P<0.05$) (Figure 7.23). Total suspended solids were greater in the San Juan than the Colorado River during trips 5 and 6 due to storms, whereas no storms occurred on the Colorado. Phytoplankton was greater in the San Juan than the Colorado during trip 8 ($P<0.05$); however, much of this difference was again due to two backwaters in Reach 1 of the San Juan River that were actually located in Lake Powell and therefore not subject to riverine processes. There was no significant difference when these two habitats were eliminated from the analysis ($P=0.27$).

Phytoplankton in backwaters of the San Juan, Colorado, and Green Rivers was compared during trips 9 through 12 (Figure 7.24). Biomass was greater in the Green than the San Juan River ($P<0.05$; Tukey's HSD), but there were no other significant differences ($P>0.05$). Overall, phytoplankton was relatively low in backwaters sampled in all rivers (<3 µg/L) during this stormy period compared to, for example, levels of about 25 µg/L observed in the one backwater at RM 153 following six months of stable flows (Figure 7.20).

Zooplankton

Abundance of zooplankton, composed primarily of cladocerans, copepods, and rotifers, was an extremely variable measure of productivity in San Juan River backwaters (Figure 7.25). There was no apparent relationship between discharge during trips (Figure 7.2) and the number of zooplankton present in backwaters (Figure 7.25). For example, zooplankton density was relatively high and variable during trips 2 and 11 when storm events occurred, but not during trip 10 which also took place during a storm.

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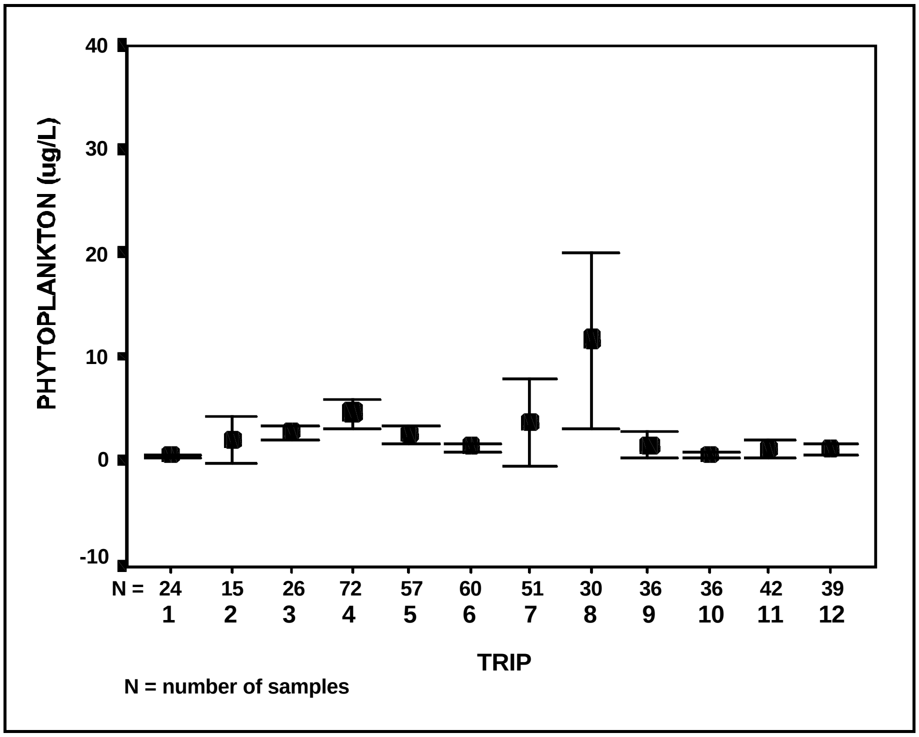

Figure 7.19. Mean Phytoplankton Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

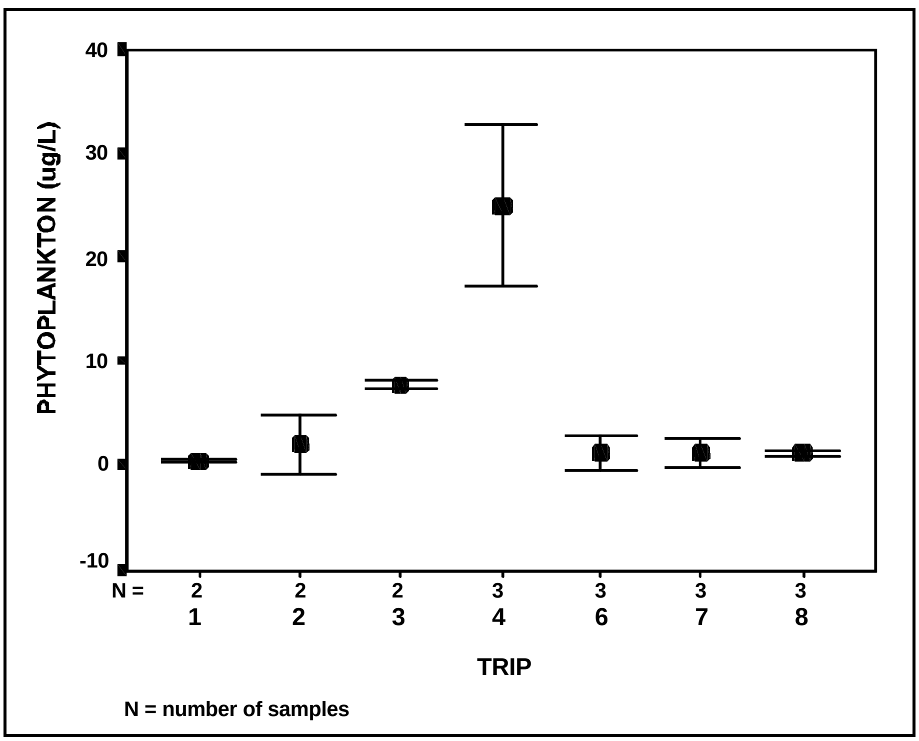

Figure 7.20. Mean Phytoplankton Biomass (±1 SE) in San Juan River Backwater at Rm 153 in Reach 5 by Sampling Trip

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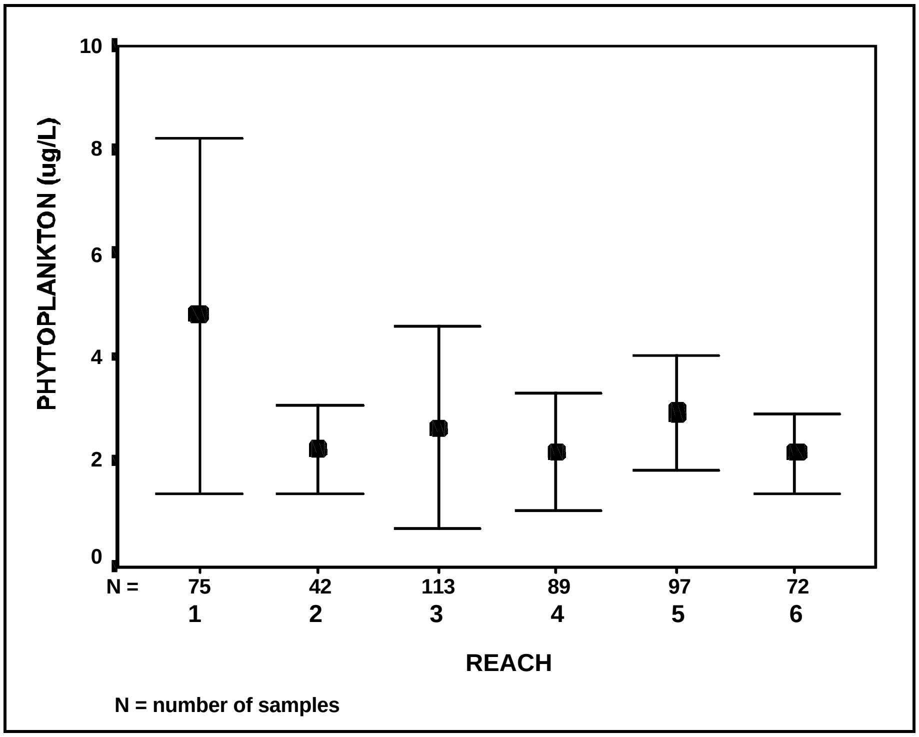

Figure 7.21. Mean Phytoplankton Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach

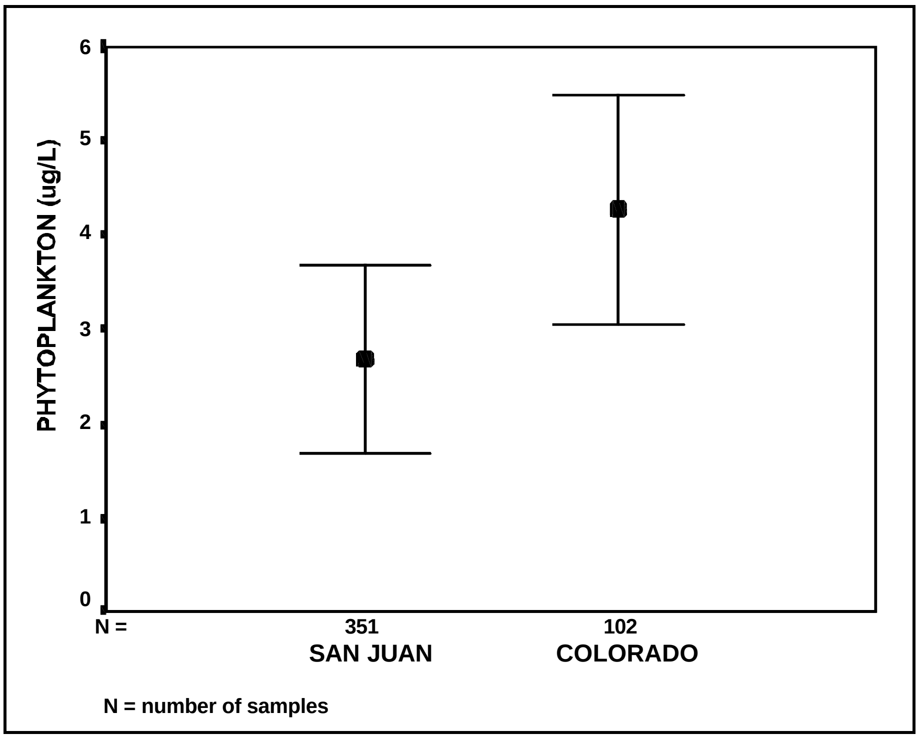

Figure 7.22. Mean Phytoplankton Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 through 12

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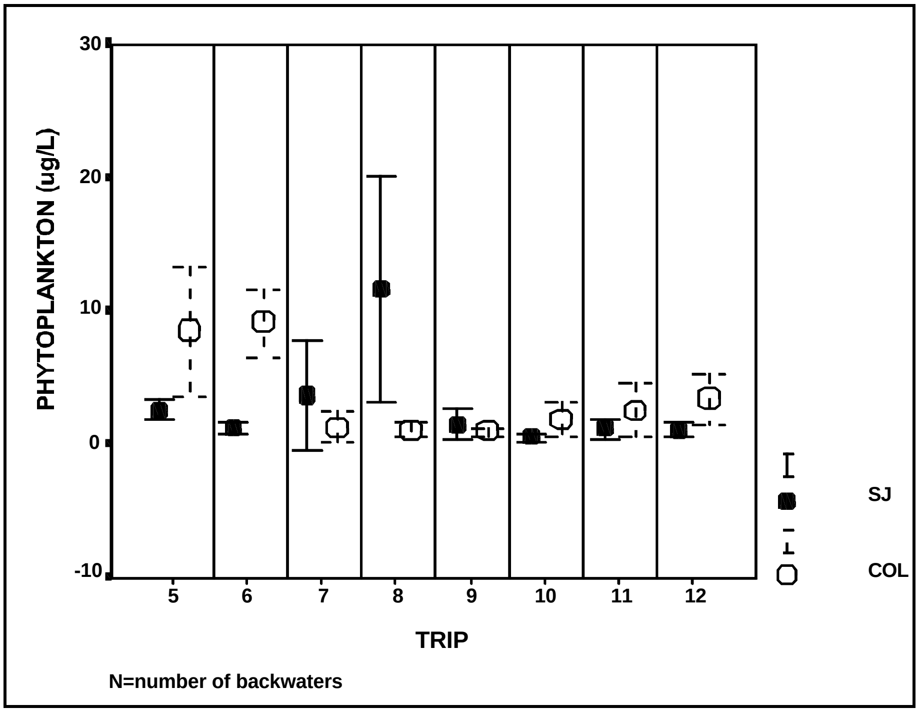

Figure 7.23. Mean Phytoplankton Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip

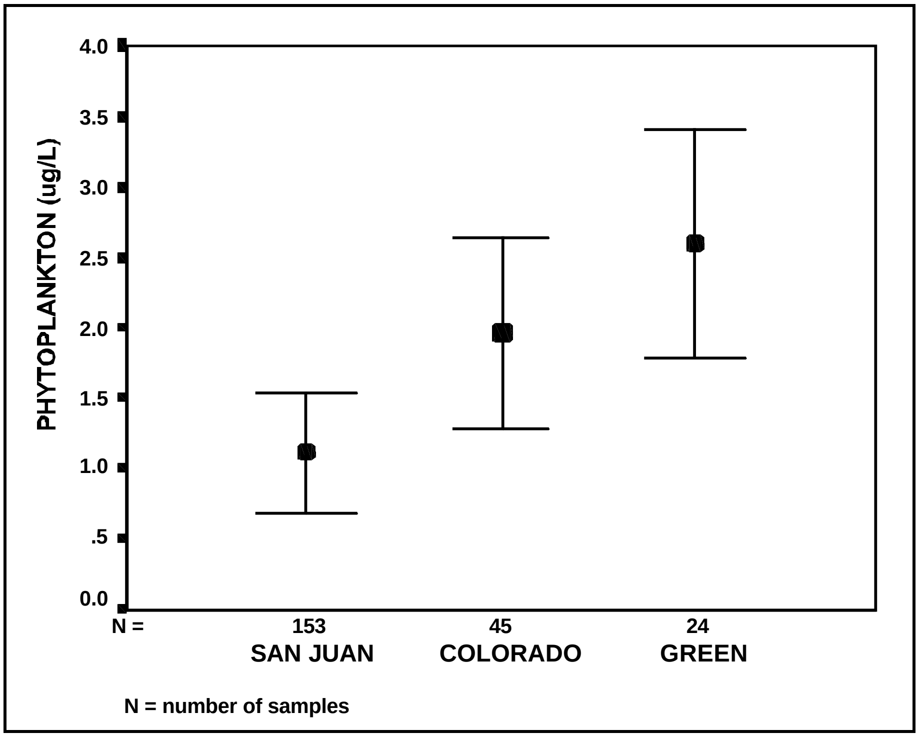

Figure 7.24. Mean Phytoplankton Biomass (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12

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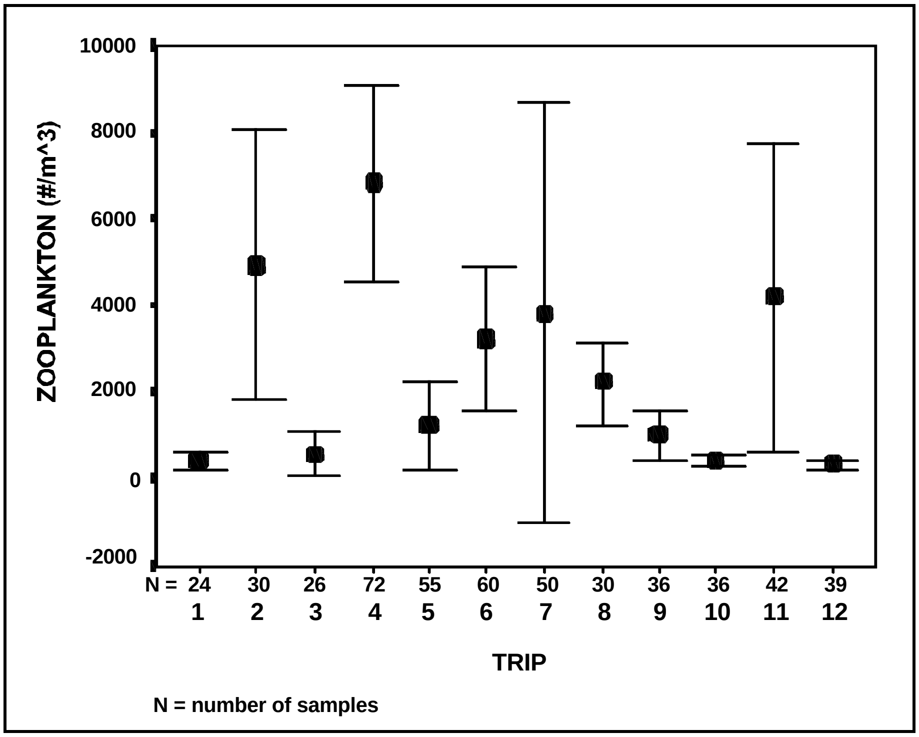

Figure 7.25. Mean Zooplankton Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

Most notably, however, there was a significant increase in zooplankton (P<0.05; Dunnett C) from the end of the monsoon period in 1995 to the pre-runoff sampling in 1996 (trip 4), while there was no change in zooplankton (P>0.05) from the end of the monsoon period in 1996 (trip 7) to the corresponding period the following spring (trip 9) (Figure 7.25). Again, the winter period from 1995-96 was characterized by stable base flows while the corresponding period during 1996-97 was relatively stormy (Figure 7.2). Therefore, stable flows appeared to result in increased numbers of zooplankton.

As stated previously, storms preceded post-runoff sampling in 1996 (trip 5) and 1997 (trip 10), but not in 1995 (trip 1). Abundance of zooplankton was relatively low (400 to 1,200 per m^3) and not significantly different between those sampling periods (P>0.05; Dunnett C) (Figure 7.25).

Thus, storms, or the lack thereof, appeared to have no discernible effect on the abundance of zooplankton in backwaters at those times. It is possible that regardless of whether or not storms have occurred previously, there are relatively few zooplankton in the backwaters so soon after runoff flows have abated. This has important implications for pikeminnow larvae potentially present in the backwaters at those times, which preferentially feed on zooplankton at this small size. However, it

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should be emphasized that it is not known whether zooplankton are limited in abundance during this period in relation to the dietary needs of these larval fishes.

There were no spatial differences in the abundance of zooplankton in backwaters of the San Juan River between reaches when averaged across all trips ($P>0.05$; Dunnett C) (Figure 7.26), although there appeared to be some spatial patterns at certain times. For example, during trip 1 when all eight geomorphic reaches were sampled, there were relatively greater numbers of zooplankton in Reach 7, and particularly, Reach 8 (Figure 7.27). It was suspected that this increased abundance in these reaches was due largely to export of zooplankton from Navajo Reservoir. The single backwater sampled in Reach 8 was approximately one mile downstream of the reservoir (Figure 1.1). However, due to high variability, there were no differences in zooplankton abundance between reaches even in this case ($P>0.05$; Dunnett C). During trip 2, zooplankton was again high and variable in Reach 8; however, there were somewhat high levels in downstream reaches at that time as well (Figure 7.28). A storm event that occurred after sampling in Reach 5 (Figure 7.2) may have resulted in some downstream displacement of zooplankton. Regardless, there were still no significant differences amongst reaches ($P>0.05$; Dunnett C).

Density of zooplankton in the San Juan and Colorado River backwaters over trips 5 through 12 did not differ ($P=0.71$; Independent samples t-test), with both rivers averaging about 2,000±1,000 individuals per m^3 (Figure 7.29). A comparison of the two rivers through time indicated fairly similar patterns, although Colorado backwaters contained greater numbers of zooplankton during trip 10 ($P<0.001$; Independent samples t-test) and trip 12 ($P<0.05$) (Figure 7.30). Storms occurred during or prior to these trips in both rivers (Figures 7.1 and 7.2), so it is possible that differences in the stage-discharge relationship between the two locations was a factor in this disparity. Stage in the Colorado River within the study area is less sensitive to changes in discharge than is the San Juan River. Over trips 9 through 12 combined, there was no difference between the abundance of zooplankton in backwaters of the Colorado and the San Juan Rivers, although this difference was nearly significant ($P=0.09$; Tukey's HSD) (Figure 7.31). Zooplankton abundance in the Green River was not significantly different from the other two rivers ($P>0.24$).

Periphyton

Temporal variations in levels of periphyton, a measure of primary production, are indicated in Figure 7.32 for all sampling trips (refer to Table 7.1 for numbering of trips). Again, these data include only Reaches 1 through 6 as only these reaches were sampled during every sampling period. The first three trips, occurring before, during, and after the 1995 monsoon season (see Figure 7.2), show a significant decline ($P<0.05$; Dunnett C) in periphyton between the first sampling after runoff in August and the next trip in September, which occurred during a storm. Nearly two months later, periphyton levels remained low and unchanged (Figure 7.32) even though only one relatively minor storm had occurred in the interim (Figure 7.2). Following nearly six months of stable discharge, periphyton levels increased dramatically ($P<0.05$) by the next sampling period in April (trip 4). Further analysis of the data collected during trips 1 and 4, when periphyton levels were relatively high, indicated that there was a distinct and consistent longitudnal pattern. Generally higher levels were observed in upstream reaches, particularly 7 and 8, during trip 1 in August (Figure 7.33).

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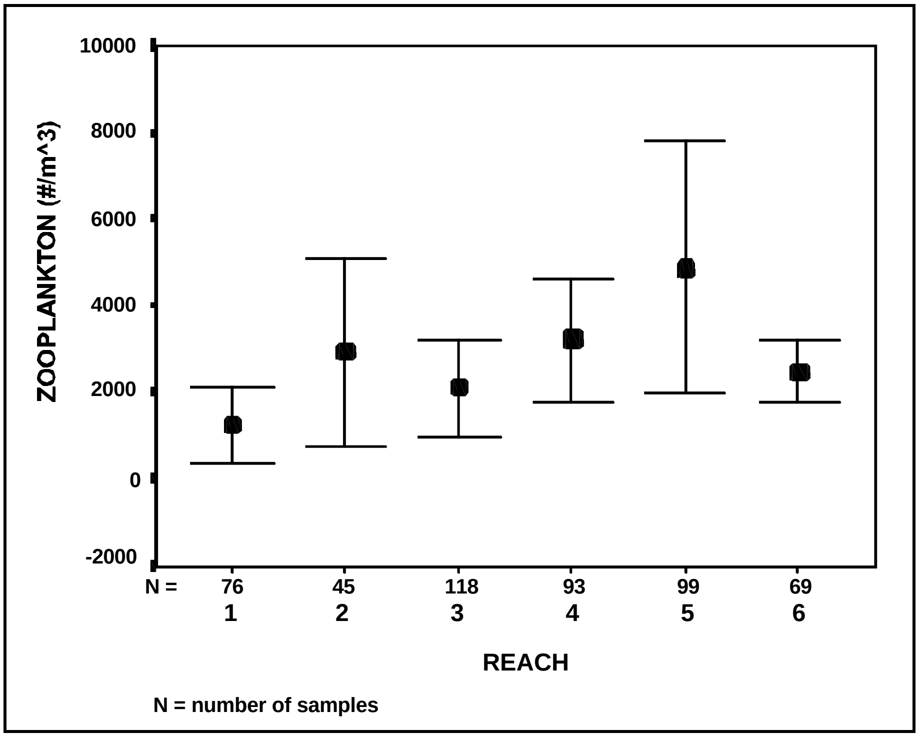

Figure 7.26. Mean Zooplankton Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach

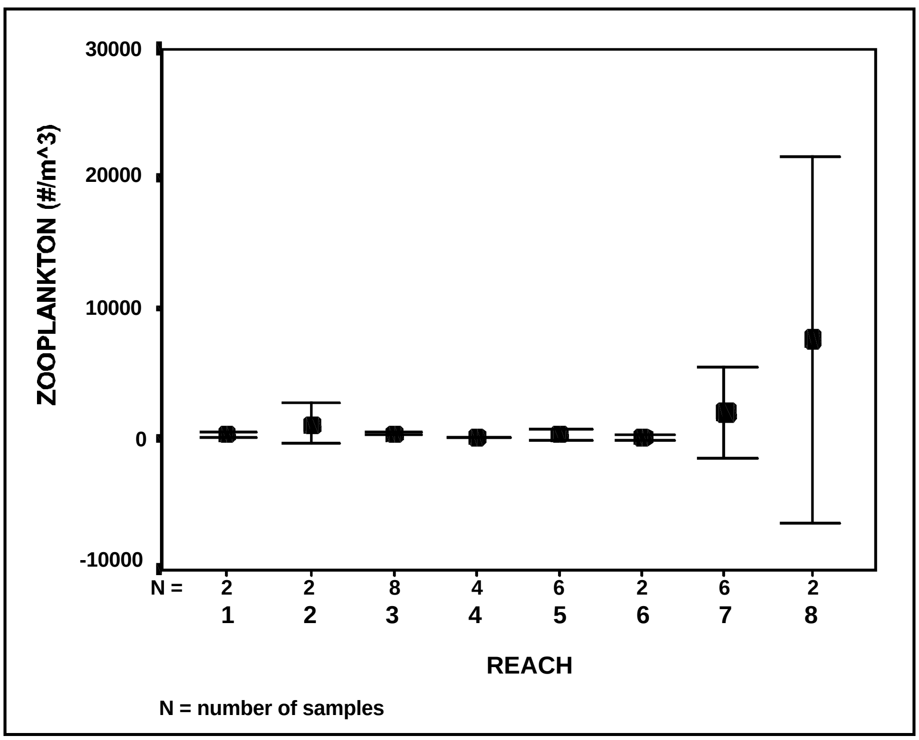

Figure 7.27. Mean Zooplankton Biomass (±1 SE) in San Juan River Backwaters During Trip 1 in August, 1995 by Geomorphic Reach

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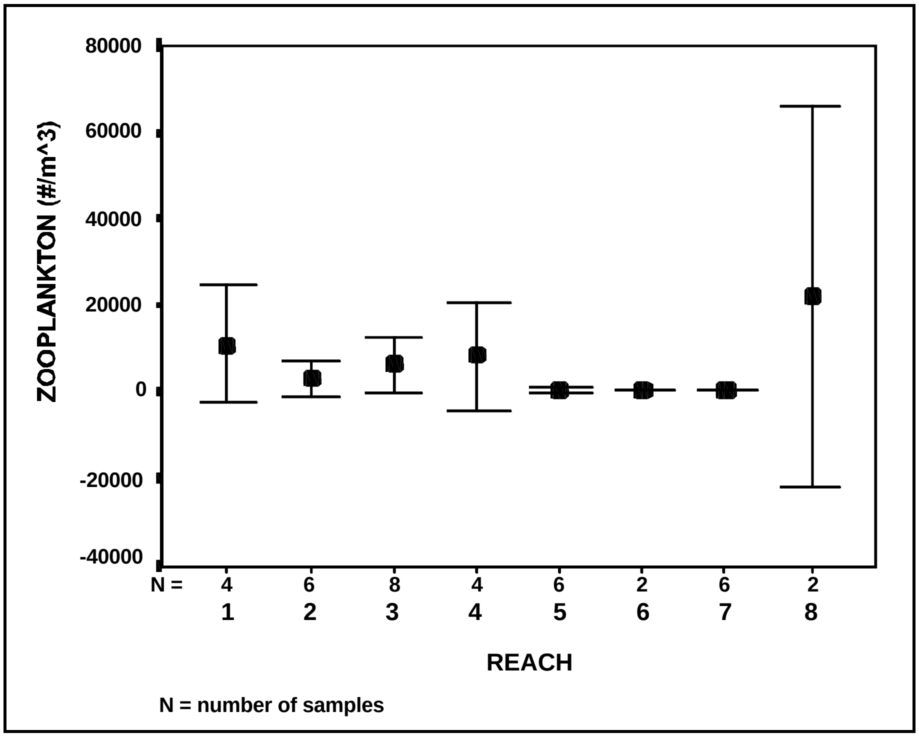

Figure 7.28. Mean Zooplankton Biomass (±1 SE) in San Juan River Backwaters During Trip 2 in September, 1995 by Geomorphic Reach

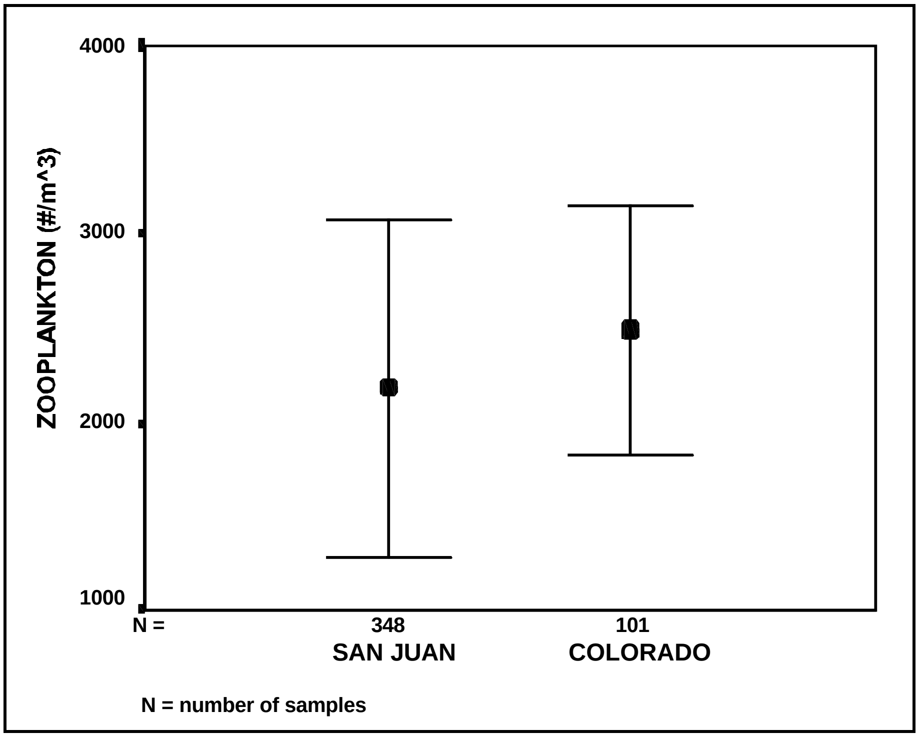

Figure 7.29. Mean Zooplankton Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 11

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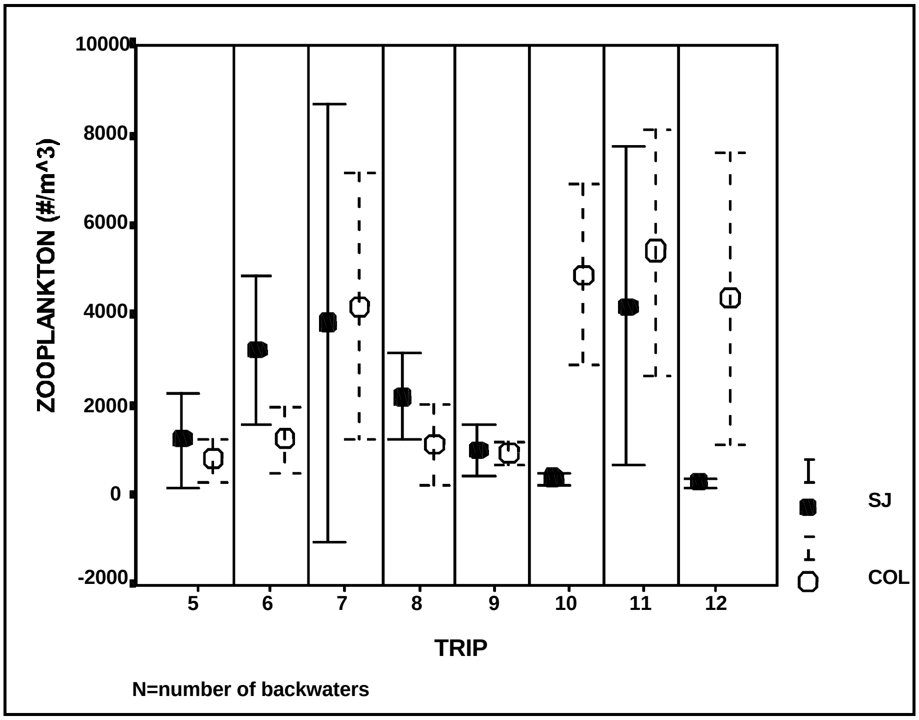

Figure 7.30. **Mean Zooplankton Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip**

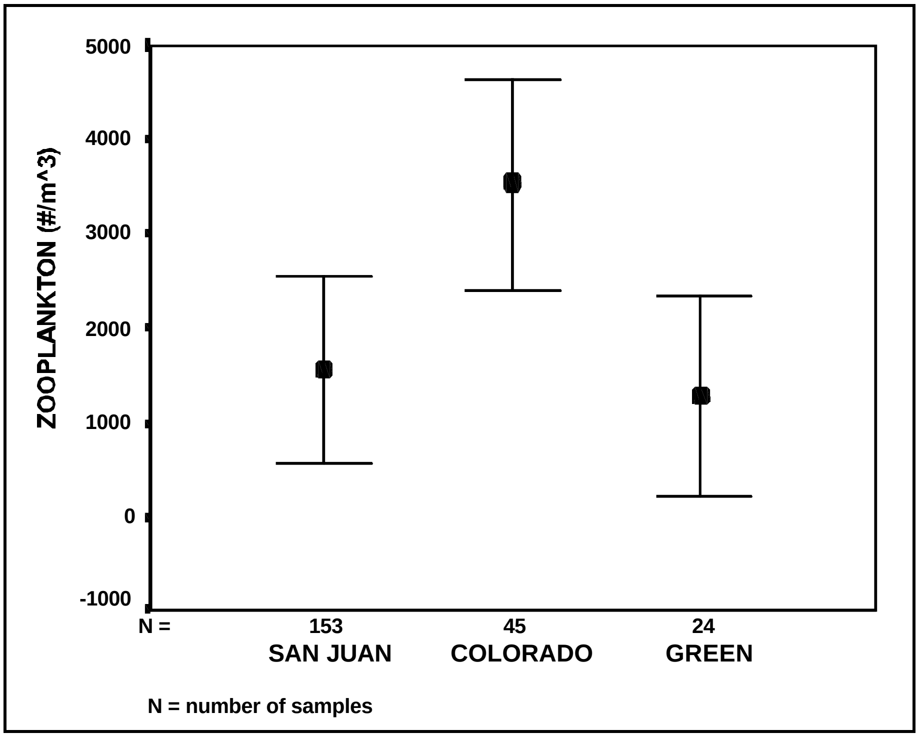

Figure 7.31. **Mean Zooplankton Biomass (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12**

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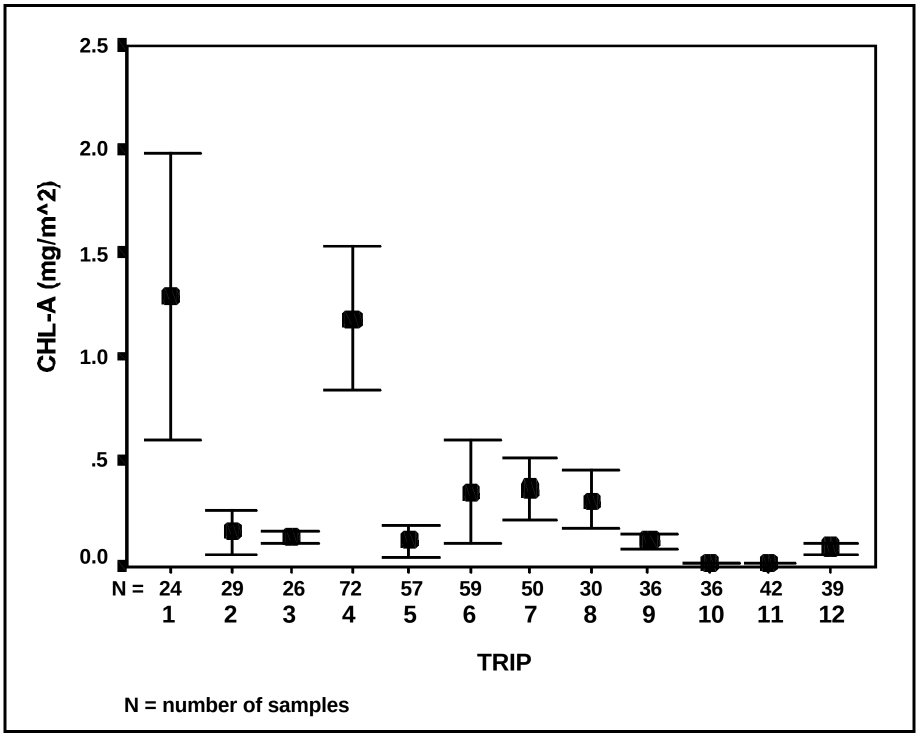

Figure 7.32. **Mean Periphyton Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip**

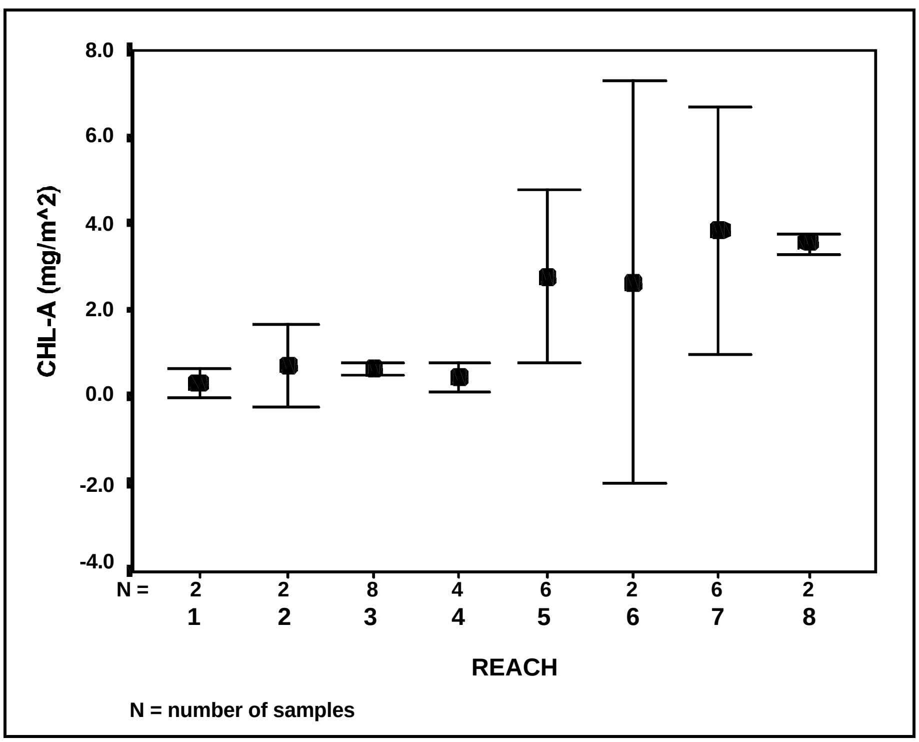

Figure 7.33. **Mean Periphyton Biomass (±1 SE) in San Juan River Backwaters During Trip 1 in August, 1995 by Geomorphic Reach**

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However, due to high variability in the data and low sample sizes, these differences were not significant (P>0.05). During trip 4 the following April, the longitudnal trend was more pronounced with Reaches 5 and 6 having the highest levels (Figure 7.34). Reach 5 was significantly greater (P<0.005) than Reaches 1 and 2, while Reach 6 was significantly greater than Reaches 1 through 4 (P<0.005). Periphyton was low in all reaches with no significant differences between reaches during trips 2 and 3 in September and November, 1995, respectively.

Following the below-average runoff in 1996, periphyton levels were significantly reduced in July (trip 5) from the pre-runoff levels observed in April (P<0.05; Dunnett C) (Figure 7.32). Those levels were also significantly lower than the corresponding post-runoff, pre-storm levels observed the previous year (trip 1) (P<0.05), which followed a substantially greater volume of runoff (Figure 7.2). Also, as stated previously, total suspended solid concentrations during trip 1 were significantly less than during trip 5 and the lowest recorded during the study (Figure 7.8). Periphyton biomass remained low over the next four trips (6-9) in August and December, 1996, and February and April, 1997 with no significant differences between trips (P>0.05). Between the August, 1996 and April, 1997 trips at least six storms producing discharges in excess of 1,500 cfs were recorded, three of which occurred between August and December (Figure 7.1). Above average rainfall in the spring produced discharge spikes in excess of 4,000 cfs prior to the April trip. Thus, a comparison of the winter period of 1996 between trips 7 and 9 and the same period in 1995 (trip 3 to 4) reveals an interesting difference between the two years. While there was a significant increase in periphyton riverwide the first season during stable winter discharges, there was no change in biomass density over the same period the following year when storms prevailed.

During the last monsoon season studied in 1997 (trips 10-12), backwaters were universally low in periphyton throughout the river with no significant differences temporally (P>0.05; Dunnett C) (Figure 7.32). Indeed, sampling during trips 10 and 11 occurred during large storms (Table 7.1, Figure 7.1) and so the backwaters sampled had only recently become inundated. Hence, there was no post-runoff, pre-storm sample obtained during the 1997 monsoon season for valid comparison to the previous two years. Inspection of the hydrograph reveals that there were few, brief periods available during the monsoon season in 1997 for sampling at base flow conditions (Figure 7.1). Sampling during the last trip, one month after cessation of the monsoons, indicated that periphyton levels in the backwaters had not improved.

Periphyton density in San Juan backwaters was compared to those in the Colorado and Green Rivers for correspondingly sampled time periods. First, the San Juan and Colorado backwater results were compared for trips 5 through 12 when both rivers were sampled. When averaged across all trips, the Colorado backwaters had significantly greater levels of periphyton (Figure 7.35) than the San Juan River (P<0.001; Independent samples t-test; equal variance not assumed (Zar 1984)). Testing individual trips revealed that there were significant differences between the two rivers only during trips 5 (July, 1996), 6 (August, 1996), and 10 (August, 1997) (P<0.005; Independent samples t-test), but that trips 5 and 6 accounted for most of the difference. Figure 7.36 illustrates the temporal differences between the two systems. Generally, the results would indicate that the Colorado River backwaters did not appear to be perturbated during trips 5 and 6, when periphyton biomass was

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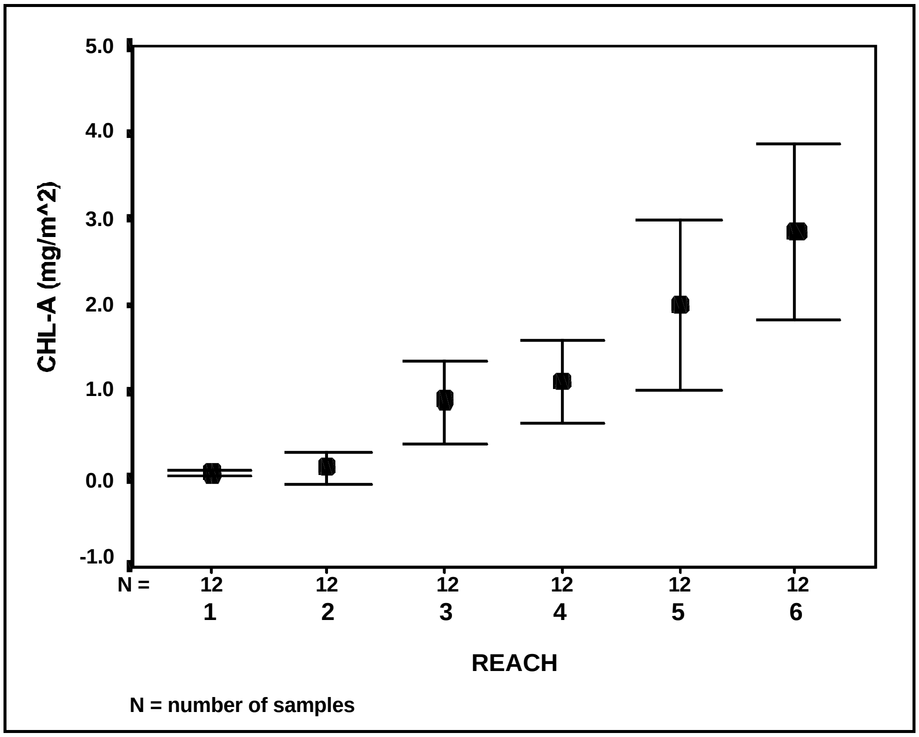

Figure 7.34. **Mean Periphyton Biomass (±1 SE) in San Juan River Backwaters During Trip 4 in April, 1996 by Geomorphic Reach**

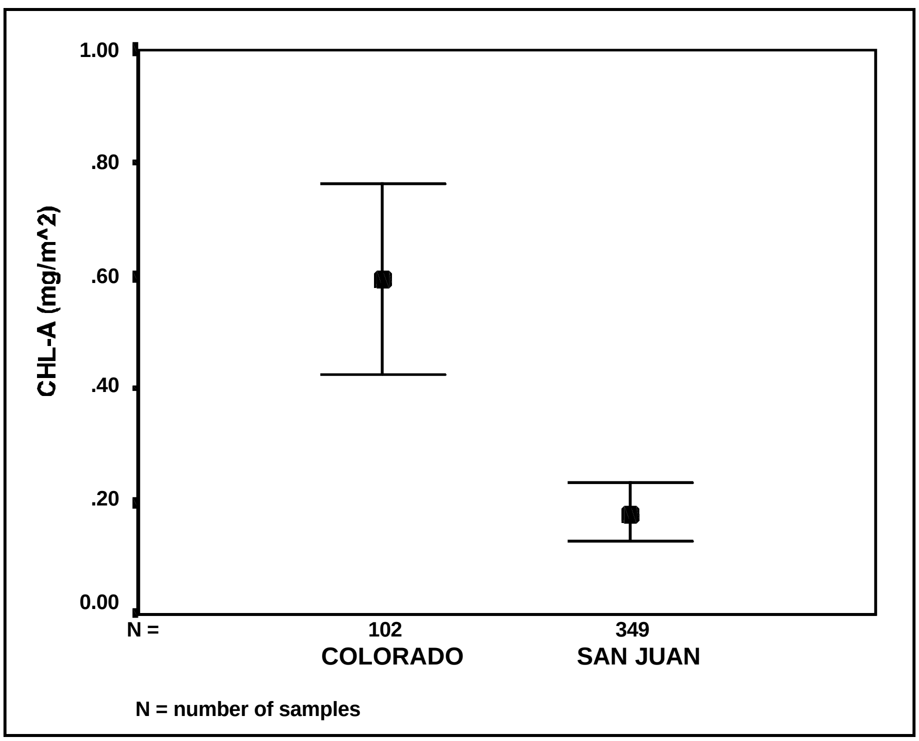

Figure 7.35. **Mean Periphyton Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 12**

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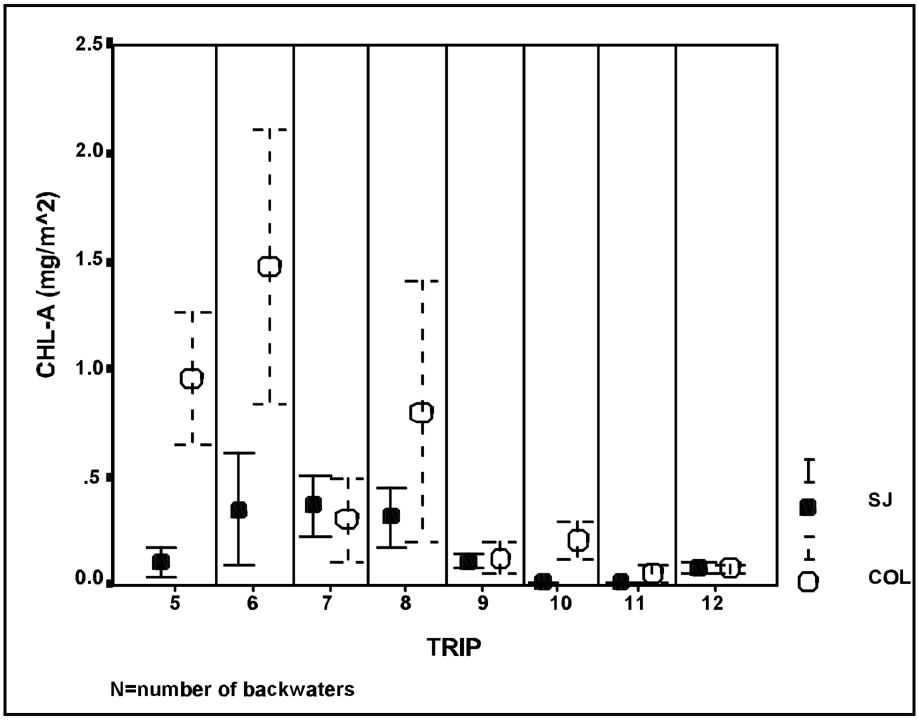

Figure 7.36. Mean Periphyton Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip

relatively high and significantly greater than the San Juan River, but that backwaters in both rivers appeared to be perturbated to some degree in every trip thereafter as evidenced by low periphyton. The San Juan, Colorado, and Green rivers were compared for trips 9-12 when sampling occurred in all three rivers. Over this time period (April-October, 1997), periphyton was significantly greater in the Colorado backwaters than both the San Juan ($P<0.001$; Independent samples t-test) and the Green Rivers ($P<0.005$) (Figure 7.37). However, the San Juan and Green River backwaters were not significantly different from each other ($P>0.98$). Mean periphyton was relatively low in all rivers (<0.2 mg/m^2) when averaged across all four trips, suggesting that backwaters in all systems appeared to be perturbated to some extent.

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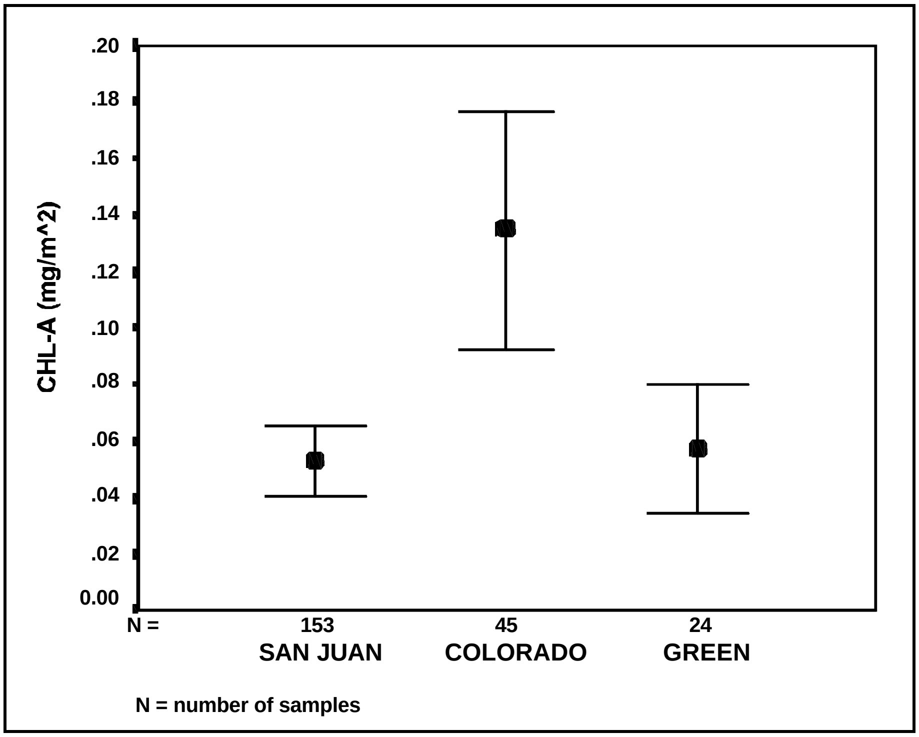

Figure 7.37. **Mean Periphyton Biomass (±1SE) in San Juan, Colorado, and Green River backwaters over the April- October 1997 Period for Sampling Trips 9 through 12**

Benthic Invertebrates

The biomass of benthic invertebrates in backwaters, primarily composed of chironomid and, to a lesser degree, ceratopogonid larvae, was relatively low during most trips on the San Juan River with the notable exception of trip 4 in April, 1996 (Figure 7.38) which followed an extended period of stable flows (Figure 7.1). Benthic invertebrate biomass was significantly greater during trip 4, than during nearly every other trip ($P<0.05$; Dunnett C). The greater abundance of invertebrates during trip 4, following stable flows, contrasted sharply with relatively low levels observed during a similar period the subsequent year in February (trip 8) and April, 1997 (trip 9) which followed a stormy period (Figure 7.1). The increase in invertebrate abundance during trip 4 was apparent to some degree in every reach sampled (Figure 7.39), although only in Reaches 1, 4, and 5 were these increases significant ($P<0.05$; Independent samples t-test).

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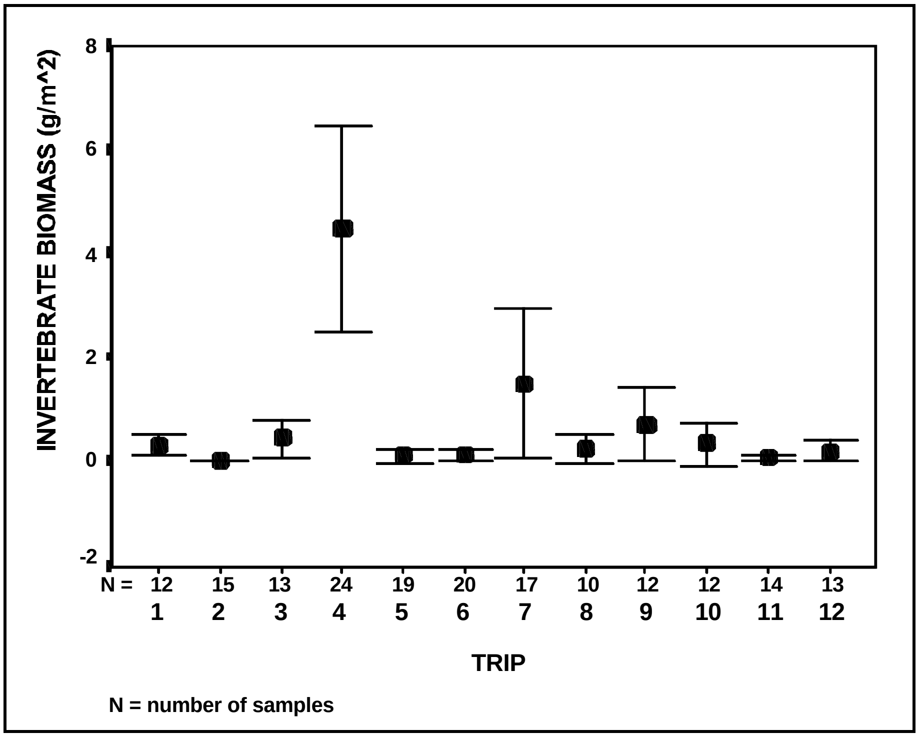

Figure 7.38. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

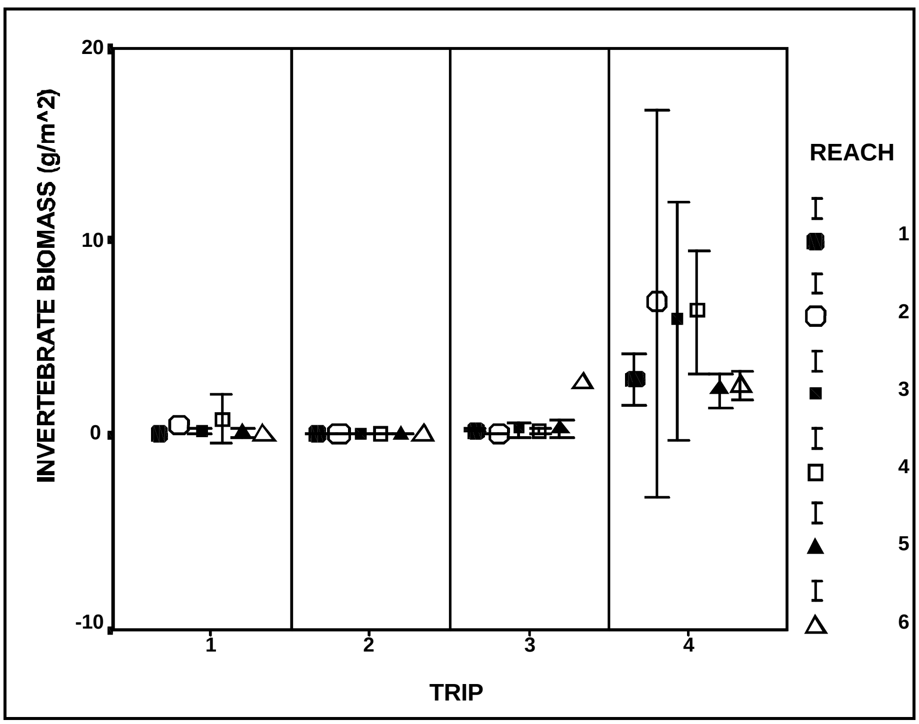

Figure 7.39. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan River Backwaters During Trips 1 through 4 by Geomorphic Reach

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Trips 4 and 7 were examined more closely to determine whether spatial trends existed during the comparatively higher invertebrate densities observed at those times. No significant differences existed by reach during either trip 4 (Figure 7.39) or trip 7 (Figure 7.30) ($P>0.05$; Dunnett C). During trip 4, there was some trend toward higher invertebrate biomass in all reaches over those during trip 3 in Reaches 2, 3, and 4 (Figure 7.39). Curiously, invertebrate abundance remained relatively low and near zero in Reaches 1, 5, and 6. During trip 7, although no differences existed between reaches, invertebrates appeared to be more abundant, although more variable upstream in Reaches 5 and 6 (Figure 7.40). Backwaters in downstream reaches were nearly devoid of invertebrates, suggesting perhaps that negative impacts associated with prior storms may have been more severe and widespread in those reaches. When averaged across all 12 trips, there were no significant differences between reaches ($P>0.05$; Dunnett C) (Figure 7.41).

Over trips 5 through 12, encompassing the period of July, 1996, to October, 1997, there was no difference in benthic invertebrate biomass between the San Juan and Colorado River backwaters ($P=0.84$; Independent samples t-test) (Figure 7.42). Both rivers averaged approximately 0.4 ± 0.2 g/m^2 over this period. Comparisons over time revealed that only during trip 6 did backwaters in the two rivers differ, with Colorado River backwaters having greater invertebrate biomass ($P<0.05$; Independent samples t-test) (Figure 7.43). One-way ANOVA indicated that there were no differences ($P=0.71$) between benthic invertebrate abundance in the San Juan, Colorado, and Green Rivers when averaged over the commonly sampled period encompassing trips 9 through 12 (Figure 7.44). Backwaters in all three rivers averaged about 0.2 g/m^2, with the most variability found in the less intensively sampled Green River.

Detritus

Benthic detritus in San Juan River backwaters was generally a highly variable parameter with few differences noted through time when Reaches 1-6 were averaged (Figure 7.45). Dunnett's C-test indicated that backwater detritus during trip 8 (February, 1997) was significantly less than trips 4 (April, 1996), 11 (September, 1997), and 12 (October, 1997) ($P<0.05$). No other differences were detected. There was no spatial pattern apparent when all trips were averaged (Figure 7.46) (Dunnett C; $P>0.05$), although levels of detritus appeared to increase slightly in Reach 1, the lowest gradient reach.

Detrital biomass was compared in the San Juan and Colorado Rivers, averaged across trips 5 through 12 when both rivers were sampled, and no significant differences were found ($P=0.58$; Independent samples t-test) (Figure 7.47). Temporal variation between the two rivers was fairly similar (Figure 7.48), with somewhat higher levels observed during later trips. Only on two occasions, trip 10 ($P<0.05$; independent samples t-test; equal variance not assumed) and trip 12 ($P<0.001$), did detritus levels differ between the two rivers, but one river was not consistently higher than the other. Detritus levels between all three rivers were compared for trips 9 through 12 combined (Figure 7.49) and no significant differences were found ($P>0.23$; Tukey's HSD).

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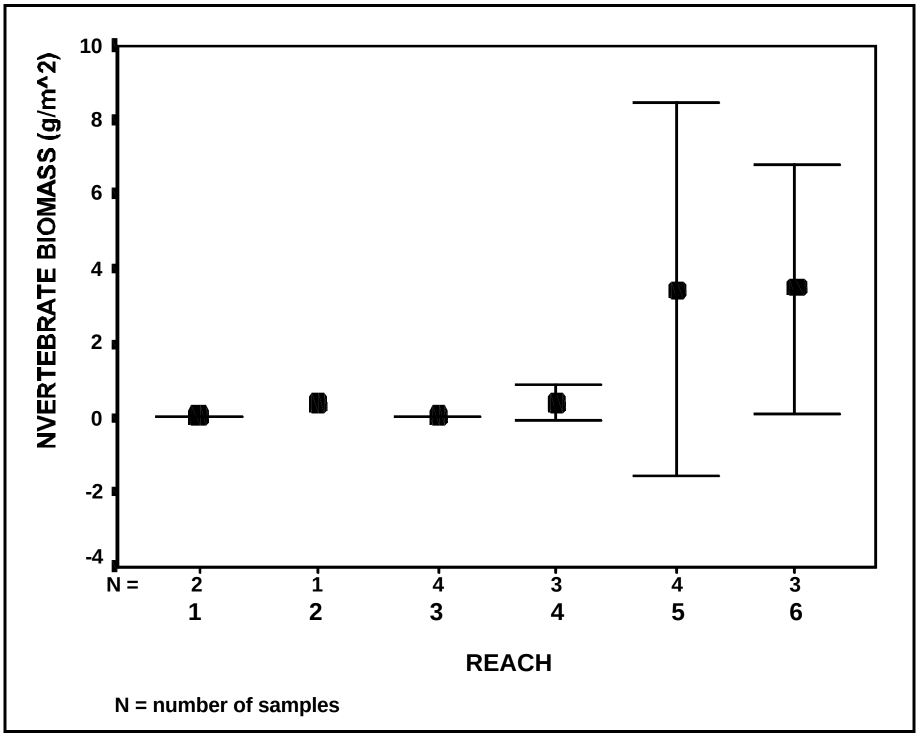

Figure 7.40. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan River Backwaters During Trip 7 in December, 1996 by Geomorphic Reach

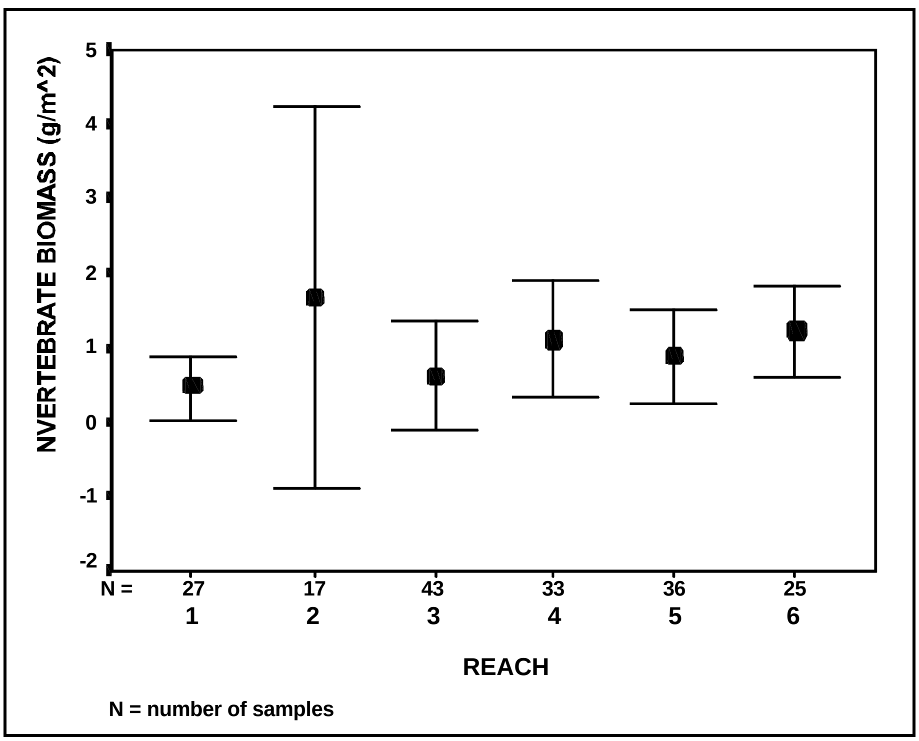

Figure 7.41. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach

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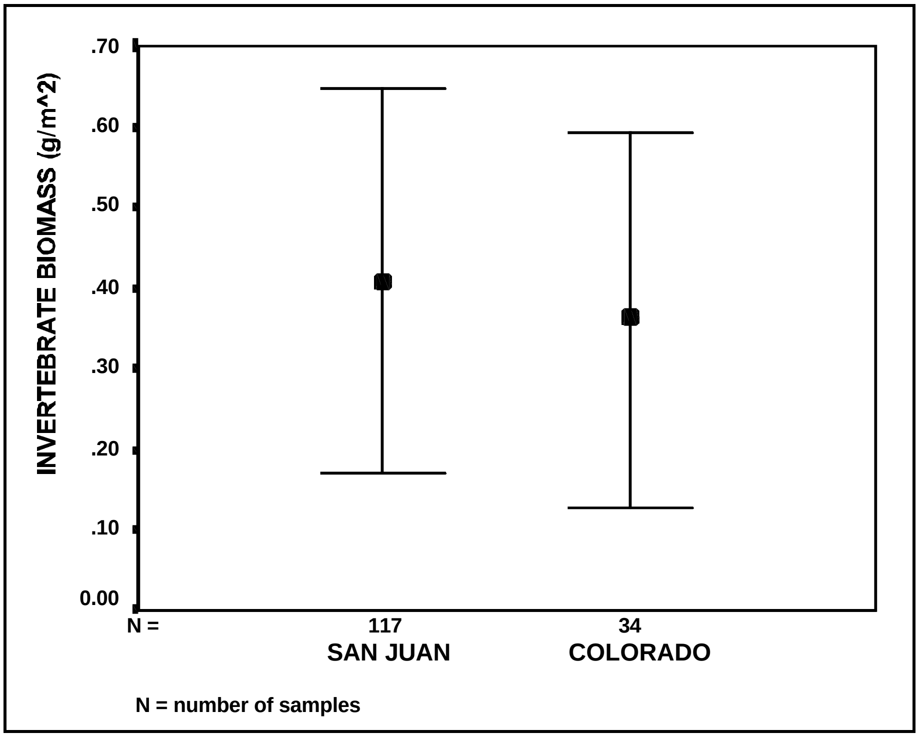

Figure 7.42. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 Through 12

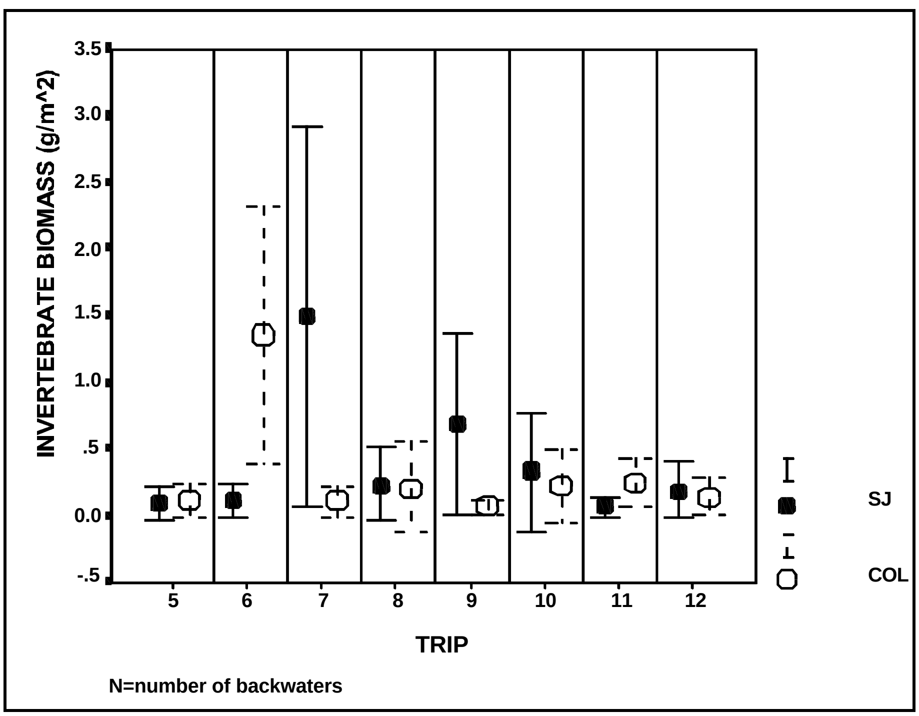

Figure 7.43. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip

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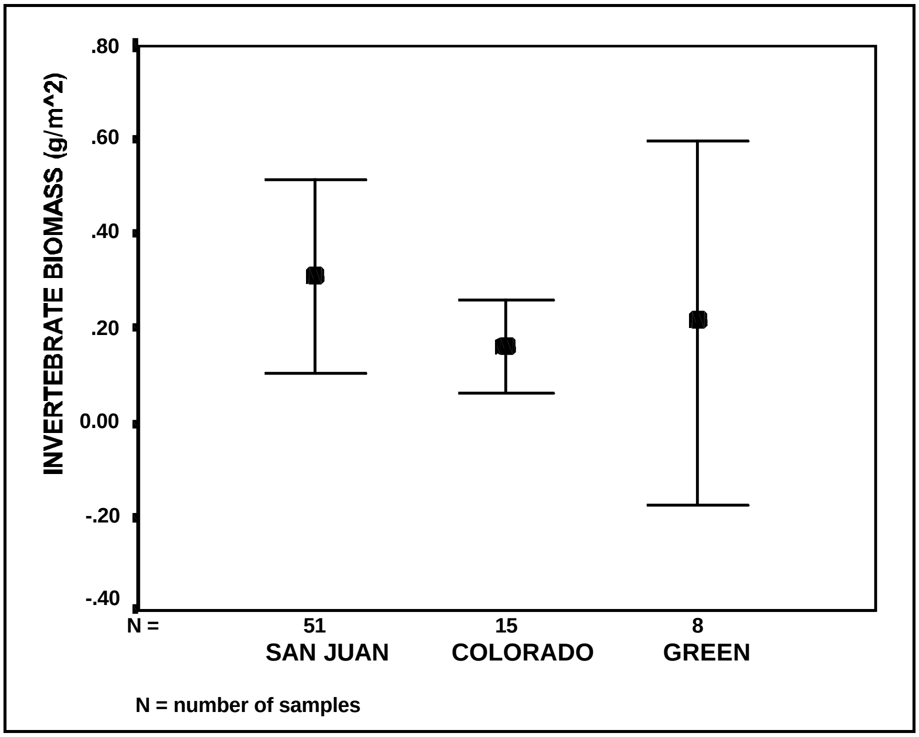

Figure 7.44. Mean Benthic Invertebrate Biomass (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12

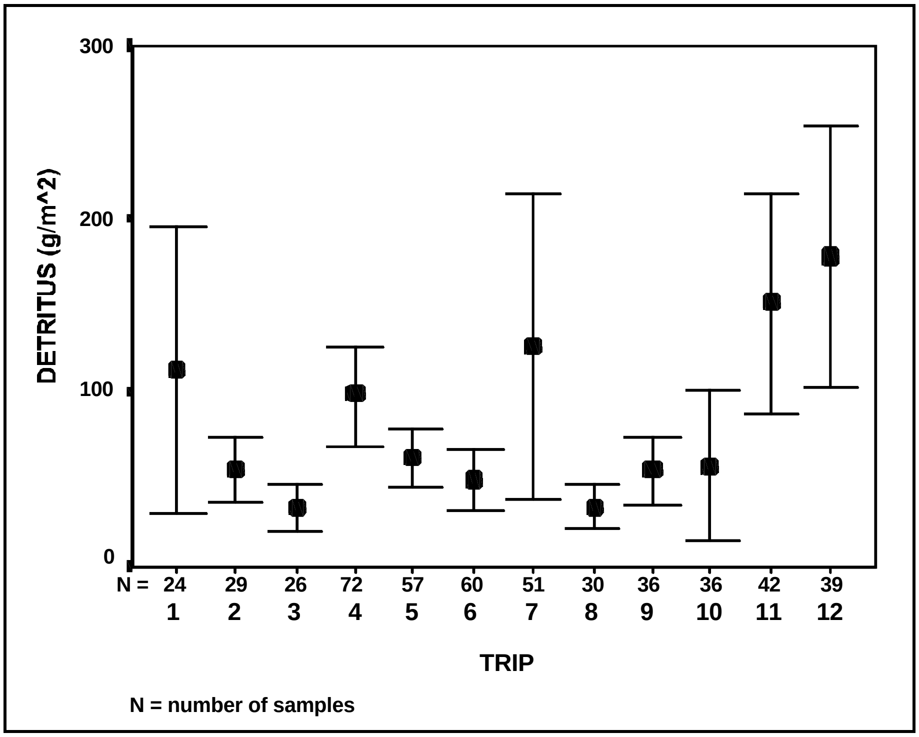

Figure 7.45. Mean Detrital Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Sampling Trip

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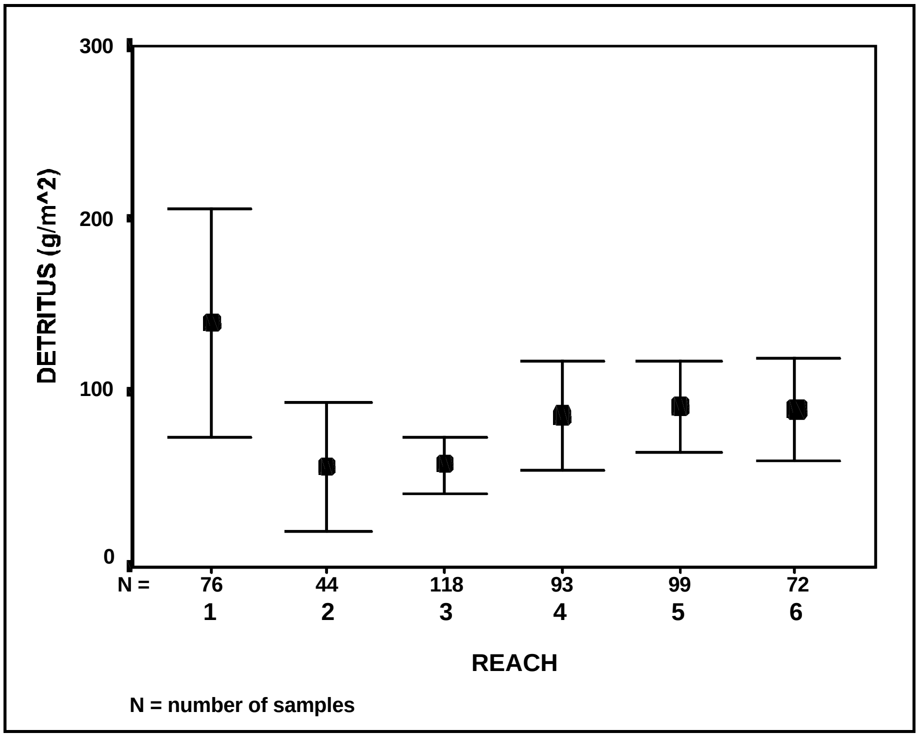

Figure 7.46. Mean Detrital Biomass (±1 SE) in San Juan River Backwaters over the 1995-97 Period by Geomorphic Reach

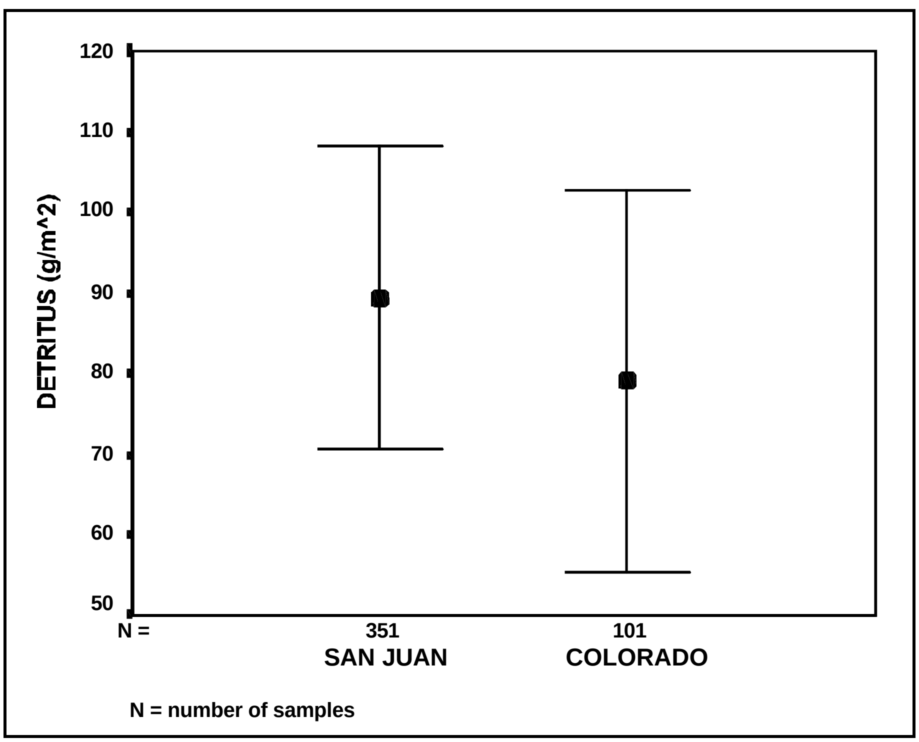

Figure 7.47. Mean Detrital Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period for Sampling Trips 5 through 12

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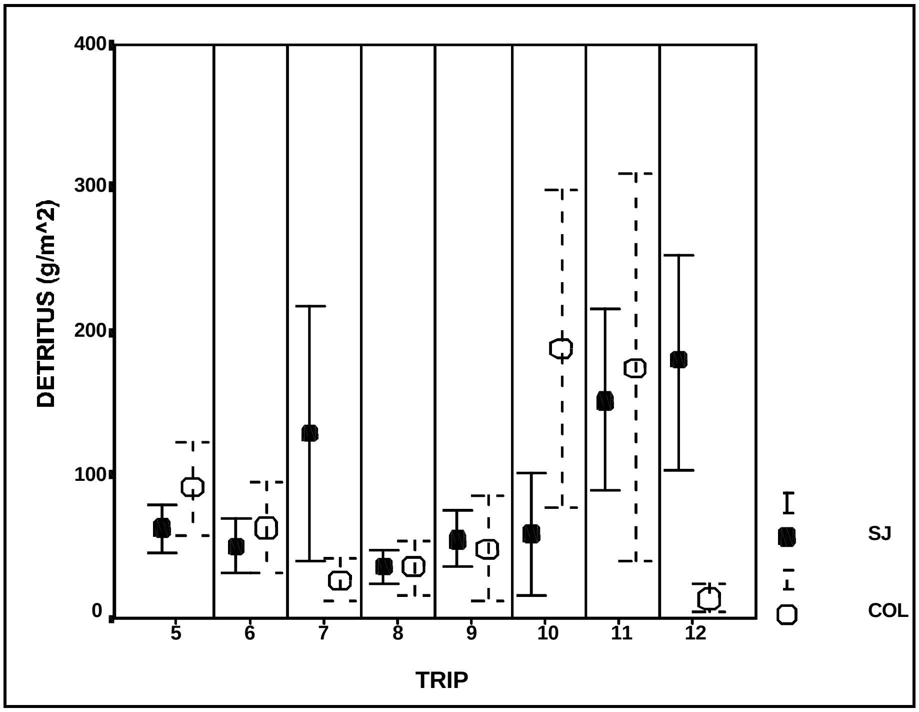

Figure 7.48. Mean Detrital Biomass (±1 SE) in San Juan and Colorado River Backwaters over the 1996-97 Period by Sampling Trip

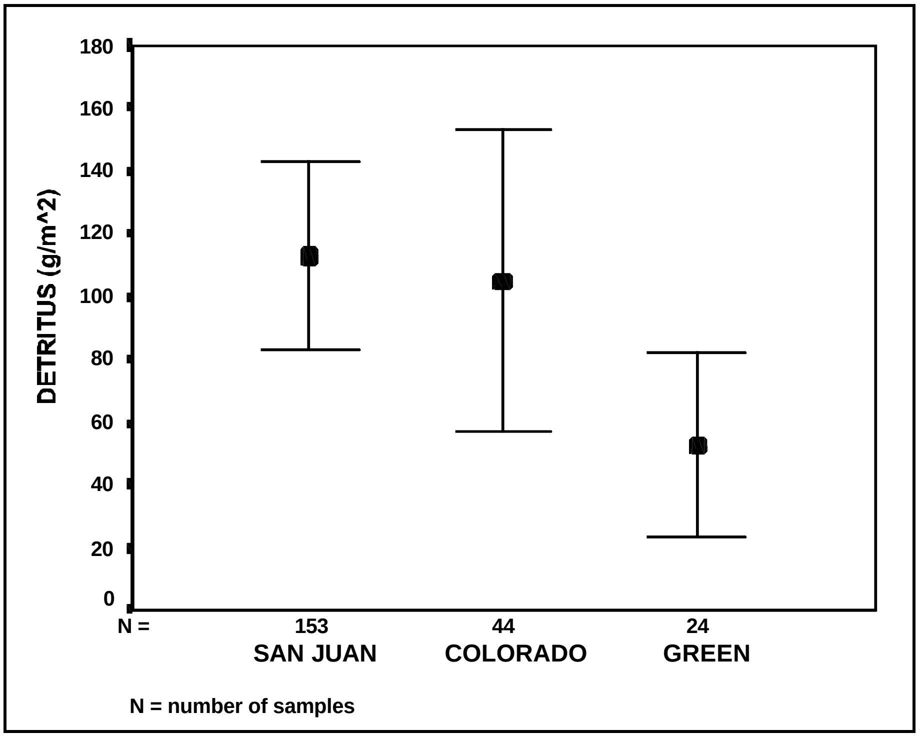

Figure 7.49. Mean Detrital Biomass (±1 SE) in San Juan, Colorado, and Green River Backwaters over the April to October 1997 Period for Sampling Trips 9 through 12

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DISCUSSION

During this investigation, the impacts of storms on several parameters indicative of the quality of backwaters in the San Juan River was observed. These parameters included phytoplankton, periphyton, and benthic invertebrate biomass. Production of these organisms was relatively low during or immediately following storm events. Conversely, productivity increased following a prolonged period of stable flows lasting five to six months. Stable flows on the order of a month or two appeared to be insufficient to result in significant increases in these parameters. When productivity was relatively high, only periphyton demonstrated a consistent longitudnal pattern, with biomass decreasing steadily downstream.

Backwater depth declined to about the same levels (0.2-0.3 m) each year after the monsoon season, apparently irrespective of the frequency or magnitude of storms. Backwater depth was highest at about 0.6±0.2 m immediately after runoff in 1995, which was the highest volume of runoff experienced during the study, suggesting some flushing of backwaters. Depths declined to the following spring to about 0.2±0.1 m and remained fairly steady thereafter to the end of the study, although changes in river stage due to storms influenced backwater depths on several occasions. Concurrently, during the period following the 1995 runoff to the following spring, the percentage of ultra fine sediment (<0.063 mm) in these habitats increased river-wide from roughly 0% to 75% (Figure 7.50), an effect that was evident in all six reaches (Figure 7.51). This suggests that accumulation of these fine sediments in the backwaters contributed to the observed decrease in mean depth. Incomplete flushing was apparent after the below average runoff in 1996 (Figure 7.50). Subsequently, percentages remained relatively high ($40%) to the end of the study in October, 1997, which constituted a rather stormy period. At least 10 storms in excess of 1,500 cfs (mean daily average) occurred over this time interval (Figure 7.2).

Other measures within backwaters were less consistent with regard to response to storms or the lack thereof. For example, zooplankton abundance increased following the period of stable flows during the fall to spring period of 1995-96, but displayed similarly “high” levels during or immediately following some storms on other occasions. There appeared to be some downstream displacement of zooplankton to lower reaches during at least one storm. Some backwaters in the lower portions of Reach 8 (Figure 1.1) may be a source of zooplankton at these times. These backwaters experience more stable flow regimes due to the lower number of tributaries located upstream and zooplankton populations within are likely augmented by limited downstream drift of zooplankton from Navajo Reservoir. Backwaters located in the upper portion of Reach 8 have no tributaries upstream and thus are not susceptible to flushing except in some instances during elevated releases from Navajo Dam.

Benthic detritus likewise increased over the prolonged period of stable flows, but was highly variable temporally with no consistent effect by storms. Storms did not appear to affect the temperature nor the amount of oxygen in backwaters. Dissolved oxygen seemed to be most influenced by temperature, with the highest levels generally occurring during the colder periods and the lowest during the warmer months.

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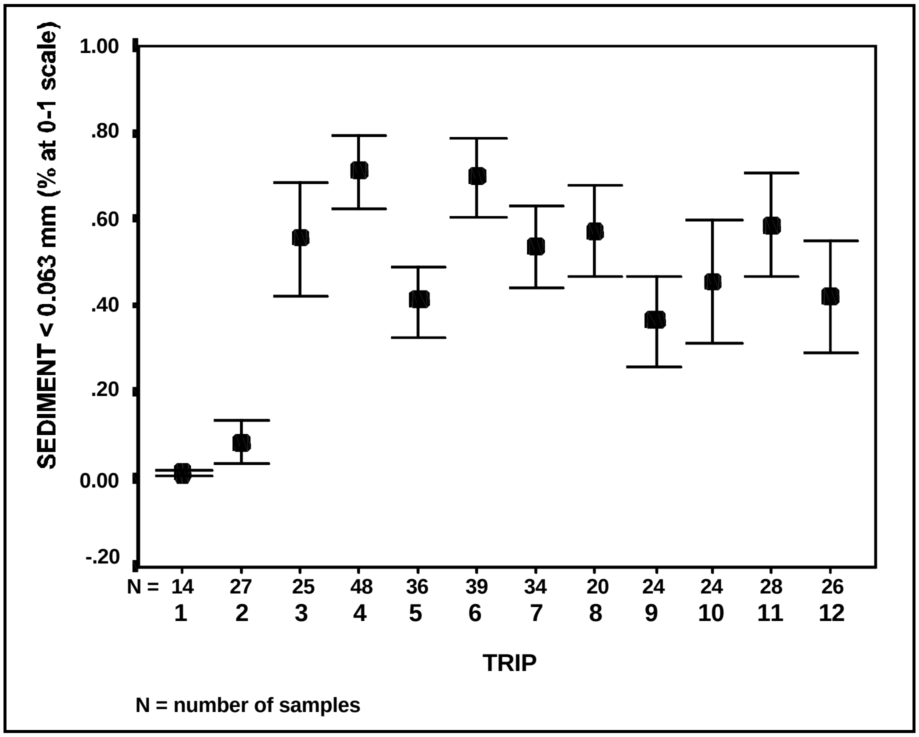

Figure 7.50. Mean Percentage (±1 SE) Dry Weight of Sediment <0.063 mm in San Juan River Backwaters over the 1995-97 Period by Trip

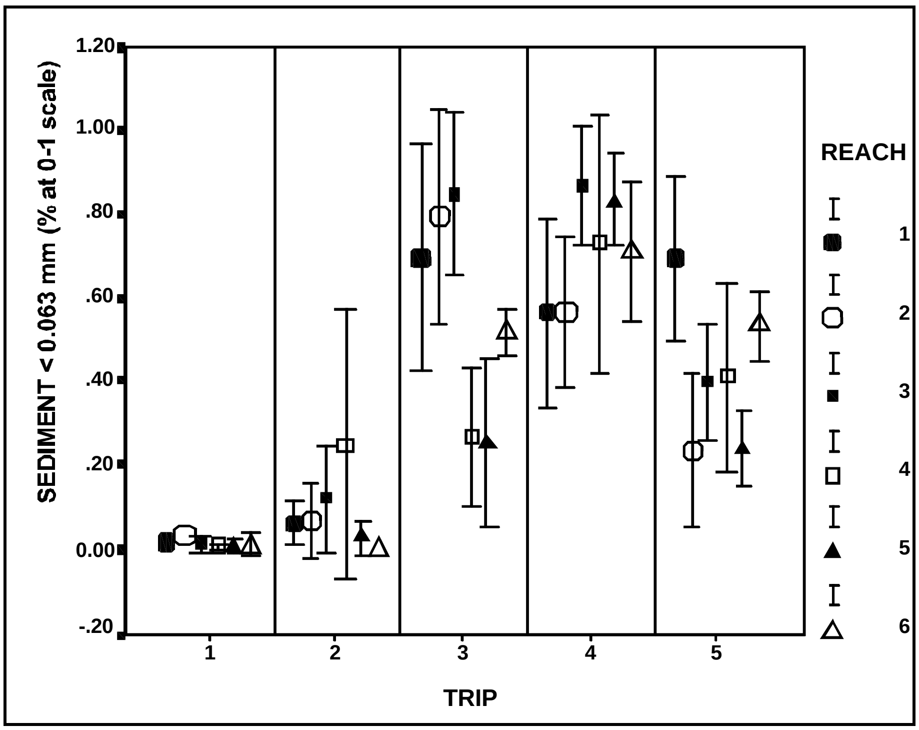

Figure 7.51. Mean Percentage (±1 SE) Dry Weight of Sediment <0.063 mm in San Juan River Backwaters over the Period of August, 1995 to July, 1996 During Trips 1 through 5 by Geomorphic Reach

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Comparisons with the Colorado River over the period from July, 1996 to October, 1997, indicated that Colorado River backwaters within the area between Moab and Potash, Utah were generally deeper and less turbid than those in the San Juan River. Backwaters in the Colorado were several Celsius degrees cooler than in the San Juan and dissolved oxygen was greater in the Colorado backwaters (-9 mg/L) on average than those in the San Juan (-6 mg/L). Production-wise, periphyton was the only parameter that was significantly greater in Colorado backwaters. Reduced turbidity in Colorado backwaters may have contributed to higher periphyton biomass through increased light penetration improving rates of photosynthesis. Cooler temperatures combined with higher primary production likely contributed to higher oxygen levels in Colorado River backwaters. Oxygen levels in San Juan backwaters were rarely reduced to the point where the existence of most fishes would be compromised, although red shiners were observed gulping air at the water surface in a number of backwaters during several sediment-laden storms.

The two key potential food organisms for young pikeminnow, zooplankton and benthic invertebrate biomass, were essentially equal between the two rivers over the time period indicated above. However, considering that the first two months after runoff (August and September) are probably the most critical for young pikeminnow, over the 1996-97 time period Colorado River backwaters contained greater numbers of zooplankton during August, 1997. Although storms occurred in both drainages during that trip (Figures 7.1 and 7.2), the magnitude of the storm in the Colorado River was only about twice base flow, while in the San Juan River it was about six times the average base flow. Also, the discharge-stage relationship in this section of the Colorado River is such that approximately twice the incremental increase in discharge is required to produce the same increase in stage as in the San Juan River. Therefore, it is very possible that most if not all of the backwaters sampled in the Colorado at that time were not flushed during the storm, while those in the San Juan River were flushed. Biomass of zooplankton and benthic invertebrates is usually lower in recently flushed than non-flushed backwaters (Kennedy and Tash 1979). This disparity between the two rivers may be a critical factor in the survival potential for larval pikeminnow which would be less likely to be exposed to physical displacement in the Colorado backwaters and should also have more zooplankton and invertebrates on which to feed.

Benthic invertebrates (primarily chironomid larvae) were significantly greater in Colorado River backwaters during the August, 1996 sampling, but not at any other time. San Juan River backwaters were perturbated by a storm event at the time of sampling, while Colorado River backwaters were not. However, a prolonged period of stable flows over the 1996-97 winter period failed to produce an increase in the biomass of invertebrates in Colorado River backwaters such as that observed in the San Juan River during the 1995-96 winter period. This apparent contradiction is difficult to explain, although it should be emphasized that the Colorado data set encompassed only one such period. It is interesting to note that catch rates of pikeminnow yoy in this reach of the Colorado River were the highest in the fall of 1996 that they have been observed since 1986 (McAda 1996). It could be speculated that predation by these fishes on invertebrates may have reduced their abundance to some degree, although this possibility seems unlikely. The reason for the lack of increase in benthic invertebrates over the stable flow period in the Colorado is not known, but it is possible that low sample sizes coupled with larger-sized backwaters and the characteristic patchiness of benthic invertebrate distribution may have been a contributing factor.

Comparisons between the San Juan, Colorado, and Green Rivers during 1997 revealed few differences in any measures. During the period from August to October, all three rivers experienced storm perturbations that generated relatively low levels of productivity. The most important parameter with respect to the diet of young pikeminnow, benthic invertebrate abundance, did not differ between these three systems over this period. These results illustrated that while less susceptible to perturbations from storms, backwaters in the lower Colorado and Green Rivers are certainly not immune to their effects.

In the final analysis, however, the ultimate determinant of the relative suitability of backwaters per se may be river gradient. Although backwaters in the lower Colorado and Green Rivers where pikeminnow yoy are relatively abundant may be less susceptible to the negative effects of perturbations on primary and secondary productivity and the physical quality of those habitats than those throughout the San Juan River, these differences may be immaterial if the opportunity for drifting pikeminnow larvae in the San Juan River to settle into these habitats is too low to provide adequate recruitment to the adult population due to high gradient. Hopefully, once the spawning adult population is large enough, sufficient numbers of larvae can be retained throughout the river and survive in substantial quantities to allow for a self-sustaining population to become established. In that event, it should be an important next step to determine whether these storm events have significant negative effects on survival and growth of these young fishes. Should this be the case, range management options may exist to ameliorate these effects. For example, the huge amounts of sediment and a portion of the water that are introduced into the river by these storms is largely contributed to by the poor condition of riparian and range areas and the unstable banks of many tributaries that have developed as a result of heavy overgrazing in the basin since the latter half of the 19^{th} century (Bliesner 1999a). Fencing of sensitive riparian zones and improvements in grazing practices are some management strategies that could be implemented to reduce these impacts.

SUMMARY AND CONCLUSIONS

1) Storms reduced the biomass of phytoplankton, periphyton, and benthic invertebrates (chiefly chironomids) in San Juan River backwaters.

2) Periods of relative stability in discharge (i.e., reduction in frequency and/or intensity of storms) on the order of months during the fall-to-spring period resulted in increased production of phytoplankton, zooplankton, periphyton, benthic invertebrates, and detritus in San Juan River backwaters. However, storms also increased the abundance of zooplankton and detritus in some river reaches on certain occasions.

3) Periphyton was the one parameter that displayed a clear longitudnal pattern following stable flows in the San Juan River, with biomass steadily declining downstream.

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4) Backwater depth riverwide in the San Juan River was relatively high following the higher magnitude runoff in 1995, but declined to lower levels thereafter during a two-year period characterized by frequent storms.

5) Reductions in backwater depth in the San Juan River over the study period coincided with increased amounts of ultra-fine sized sediment accumulation in the backwaters.

6) Backwater depth riverwide declined to about the same average levels (0.2-0.3 m) following all three monsoon seasons studied from 1995 to 1997, apparently regardless of storm intensity during the monsoon period.

7) Dissolved oxygen in San Juan River backwaters was inversely related to water temperature, but was rarely reduced to less than 3 mg/L in even the warmest backwaters.

8) Colorado River backwaters within the Moab to Potash reach tended to be deeper, less turbid, cooler, and more oxygenated than San Juan River backwaters over the same time period.

9) Colorado River backwaters contained higher levels of periphyton over the same time period than San Juan River backwaters riverwide, while other biological parameters were similar on average.

10) During the monsoon period in 1997 when storms were prevalent, San Juan, Colorado, and Green River backwaters contained similarly low primary and secondary productivity, indicating physical disturbances to the backwaters throughout all three drainages.

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